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BACTERIAL AEROSOLS FROM A FIELD SOURCE DURING MULTIPLE-SPRINKLER IRRIGATION: DEER CREEK LAKE STATE PARK, OHIO

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An evaluation of microbiological aerosols resulting from the spray irrigation of wastewater under known atmospheric stability conditions was performed during July and August 1978 at the Deer Creek Lake land treatment system in Ohio. In the experiment, ponded chlorinated wastewater was sprayed onto a 6-acre test area with 96 impact sprinklers representing a multi-source field aerosol distribution system. Approximately 99.9% of the wastewater applied to the 23-hectare test area fell within the area of influence of the sprinkler

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20. Abstract (cont'd)

(about a 20-m diam circle around the sprinkler riser) with only 0.10% of the applied wastewater aerosolized. Indigenous total aerobic bacteria in the wastewater and resultant aerosols were sampled and analyzed. Aerosol particle size-discriminating samplers and high-volume electrostatic precipitator samplers were positioned at upwind and at near (21-50 m) and far (200 m) downwind sampling stations. Fluorescent dye studies were also performed to characterize the aerosol cloud without the effects of biological decay. During all of the aerosol tests continuous on-site meteorological measurements were made and wastewater chemical parameters monitored. The microbiological aerosol sampling immediately downwind of the spray field showed significant aerosol levels above background. Bacterial aerosol concentrations 200 m downwind were about 92% less than those at the 21-30 m sampling point. The bacterial aerosol levels were approximately the same as the background concentration when the mean height of the spray arcs was exceeded (about 3.05 m). The median size of aerosol particles containing viable bacteria 30 m downwind was 2.6 μm. Seventy-five percent of these particles fell within the range of pulmonary deposition, less than 5 μm. The median size of bacterial aerosol particles upwind was significantly larger, being 4.3 μm. It is probable that these particles contributed somewhat to the larger median particle size of 3.0 μm observed at 200 m. Dye aerosols retained 2 to 3-fold greater levels in relation to source strength than bacterial aerosols, thus indicating some biological decay (die-off) in bacterial aerosols through the aerosolization process. The prevalence of certain bacterial populations was altered through aerosolization but the aerosol populations included relatively greater numbers of gram-positive bacteria.

PREFACE

This report was prepared by Dr. Howard Bausum, U.S. Army Medical Bioengineering Research and Development Laboratory (USAMBRDL), Roy Bates, Dr. Harlan McKim, Patricia Schumacher and Bruce Brockett, all of the Research Division, U.S. Army Cold Regions Research and Engineering Laboratory and by Dr. Stephen Schaub, USAMBRDL. The CRREL portion of the study was conducted as part of the Land Treatment of Wastewater Research Program under the direction of Dr. Harlan L. McKim, Program Manager. The overall project was a jointly funded effort established between CRREL and USAMBRDL. Other agencies participating in the study were the Environmental Effects Laboratory at the Waterways Experiment Station, the Huntington District Corps of Engineers, the University of Minnesota, the Ohio Park Service, the Ohio State University, and the University of Texas at San Antonio. This study was funded under Civil Works Project CWIS 31280, Evaluation of Existing Facilities for Wastewater Land Treatment. Robert Emerson of the Atmospheric Sciences Laboratory (ASL) Maynard, Mass., Meteorological Team, helped to install the meteorological instruments following guidelines specified in the agreement. Specialist Robert Romano also of ASL remained on site to assume operation of meteorological instrumentation and to make specific measurements during testing.

The manuscript of this report was technically reviewed by J. Bouzoun and G. Abele of CRREL and by R. Miller and J. Glennon of USAMBRL.

Waterways Experiment Station provided the mobile chemistry laboratory and valuable assistance of Richard A. Shafer and Susie Mathews, who were on site throughout the project. Joseph Gates, of the University of Minnesota, provided invaluable laboratory support throughout the project, and Kathy Green assisted in running the biological analyses.

Basil Green, Resident Engineer for the Deer Creek Lake Project, and his staff, and David Lambert of the Huntington District Corps of Engineers provided major logistic and field support. E.W. Larson, U.S. Army Medical Research Institute of Infectious Diseases, and Dr. C.A. Spendlove, Dugway Proving Ground, made available the high-volume air samplers. Jerry Highfill, USAMBRDL, helped with statistical aspects of the work and John Glennon and Mitchell Small, USAMBRDL, provided helpful discussions, particularly in the planning stage. Leonard Stanley of CRREL assisted in modifying the plume dispersion equations.

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INTRODUCTION

This study was conducted to obtain quantitative data on the strength, dispersion, particle size and decay of bacterial aerosols resulting downwind from a spray irrigation land treatment system. At the time of this study the buffer zone was 800 m for this system. This value seemed very conservative and thus the study was initiated to determine the distribution of aerosols downwind from the land treatment system and whether spray irrigation methods are any more hazardous to human health than conventional methods due to this distribution.

Land treatment of wastewater by spray irrigation is an important alternative to advanced wastewater treatment. From a public health standpoint, this practice raises the question of the potential dispersal of pathogenic bacteria, viruses and other organisms, especially through downwind travel of infectious aerosols. Some aspects of this problem have been addressed in several studies (Reploh and Handloser 1957, Bringmann and Trolldenier 1960, California Water Pollution Control Board 1957) in which data were obtained on the travel of coliform bacteria from spray operations using undisinfected raw or settled sewage. In an earlier two-phase study conducted by USAMBRDL at Ft. Hauchuca, Arizona (Bausum et al. 1976, Bausum et al, 1978, Sorber et al. 1976, Bausum et al. in prep.) field data on aerosol levels and aerosol dispersal for total aerobic bacteria, coliforms, *Klebsiella* and artificially seeded f2 coliphage were presented. A predictive model of plume travel based on Turner's (1970) modification of the diffusion equation of Pasquill (1961) was used in the analysis Also, tests using known concentrations of fluorescent dye were conducted so that comparisons of the microbial aerosols with dye aerosols (which lack a biological decay factor) could be made.

The primary purpose of this project was to measure airborne bacterial concentrations resulting from the spray irrigation of wastewater at Deer Creek State Park, Ohio. Monitoring of aerosol distribution downwind from the spray area was a major aspect of the research and development effort at this site. Measurements of atmospheric biological and meteorological conditions and of wastewater parameters during the study period, 1 July through 15 August 1976, were conducted on site. These data are currently being analyzed utilizing a computer model which predicts the aerosol particle densities downwind under various atmospheric conditions. This study will contribute to development of revised health criteria guidelines for the possible establishment of buffer zones between spray sites and populated areas.

The Deer Creek Lake study differs greatly from earlier experiments due to the nature of the spray source. At Deer Creek Lake, 96 spray heads were used, whereas in other studies only a single spray head was used. Wastewater characteristics and climatological factors were also quite different from those examined by USAMBRDL at the Ft. Hauchuca site. The collection of meteorological information during the Deer Creek Lake study was greatly improved by incorporating more sophisticated equipment into the test array. This provided more accurate input for mathematical predictive models of aerosol decay.

The pattern of aerosol sampler deployment of the present study incorporated knowledge developed in earlier studies. Most sampling equipment was placed at two close-range distances downwind from the spray field (usually 30 and 50 m) and aligned on 3-m centers at each distance. This was done to provide multiple observations at these critical points, thereby providing better assessment of sampler-to-sampler variability and better definition of the early part of the curve of aerosol strength vs downwind distance in terms of dieoff or dispersion. This close-in aerosol level can be related to known source strength, and this relation can be observed in both the presence and absence of biological dieoff. Projections of aerosol behavior and concentrations downwind can be studied through the use of both mathematical modeling and actual samples collected at greater distances.

OBJECTIVES

The primary objective of the study was to expand the available data base on the distribution of aerosolized wastewater microorganisms from which design criteria can be developed for the Land Treatment of Wastewater Program. Specifically, the Deer Creek Lake site was evaluated to obtain aerosol data at a small recreational site, where relatively weak wastewaters received minimal treatment but extended storage before spraying onto land.

A secondary objective was to determine the meteorological parameters affecting or influencing the downwind stability of aerosols resulting from the spray application of wastewater. This report will assist in determining the extent of buffer zones required for human protection.

DESCRIPTION OF STUDY

Site Description and Treatment of Wastewater

The Deer Creek Lake land wastewater treatment project was designed and constructed by the U.S. Army Corps of Engineers, Huntington District, as a part of the Corps' research and development effort in land treatment of wastewater. The site is located in the Scioto River Basin of central Ohio about 35 miles southwest of Columbus and 5 miles south of the town of Mt. Sterling, and includes portions of Pickaway, Fayette and Madison Counties (see Fig. 1). The project site treats wastewater from a campground at Deer Creek Lake State Park. The spray fields and aerosol sampling site are in an open area, on a fairly level plateau. Mean elevation of the area is 265 m above sea level. The soil is composed of a clay-silt mixture that has high water retention capacity.

Raw wastewater is pumped from the campground to a stabilization lagoon (lagoon 1, Fig. 2) which has a mean depth of 1.7 m (5 ft). The mean residence time in the stabilization lagoon is approximately 90 days. The effluent from the primary stabilization pond passes through a chlorine contact chamber (1 hour contact time, 2 ppm total residual chlorine) into a holding basin having a mean residence time of 4-6 days. The effluent is then pumped to the spray field through a 25-cm (10-in.) main where it is applied to four test areas by spray irrigation.

At Deer Creek Lake, effluent is applied to a 4.9-hectare (12-acre) test site. A complete drainage collection system returns treated water to a local creek. In this study only two 1.2-hectare (3-acre) test areas were used because the test design model could conveniently accommodate only 100 spray nozzles or sample points. The last three rows of nozzles in the spray field plots 1 and 2 (Fig. 2) were removed giving an approximately square 2.45-hectare (6-acre) area of wastewater application and aerosol input. Each area is served by four lateral wastewater distribution pipes, each bearing 15 Rainbird spray heads. The distance between laterals is 18.3 m and between spray heads on each lateral 12.2 m. Sprinkler heads are 0.6 m above ground level with a nozzle size of 0.40-cm (5/32 in.) internal diameter. Pressure measured at the spray nozzles is 4.1-4.2 kg/cm^2 (56-59 psi) which remained constant across the spray field during testing. The flow is about 18.9 liters (5 gal.) per nozzle/min for a total of 1910 liters/min (480 gal./min). The area wetted by spray from a single head averages 13 m (42.5 ft) in radius, while, at maximum, the spray arc reaches a height of 2.7 m (9 ft) above ground level.

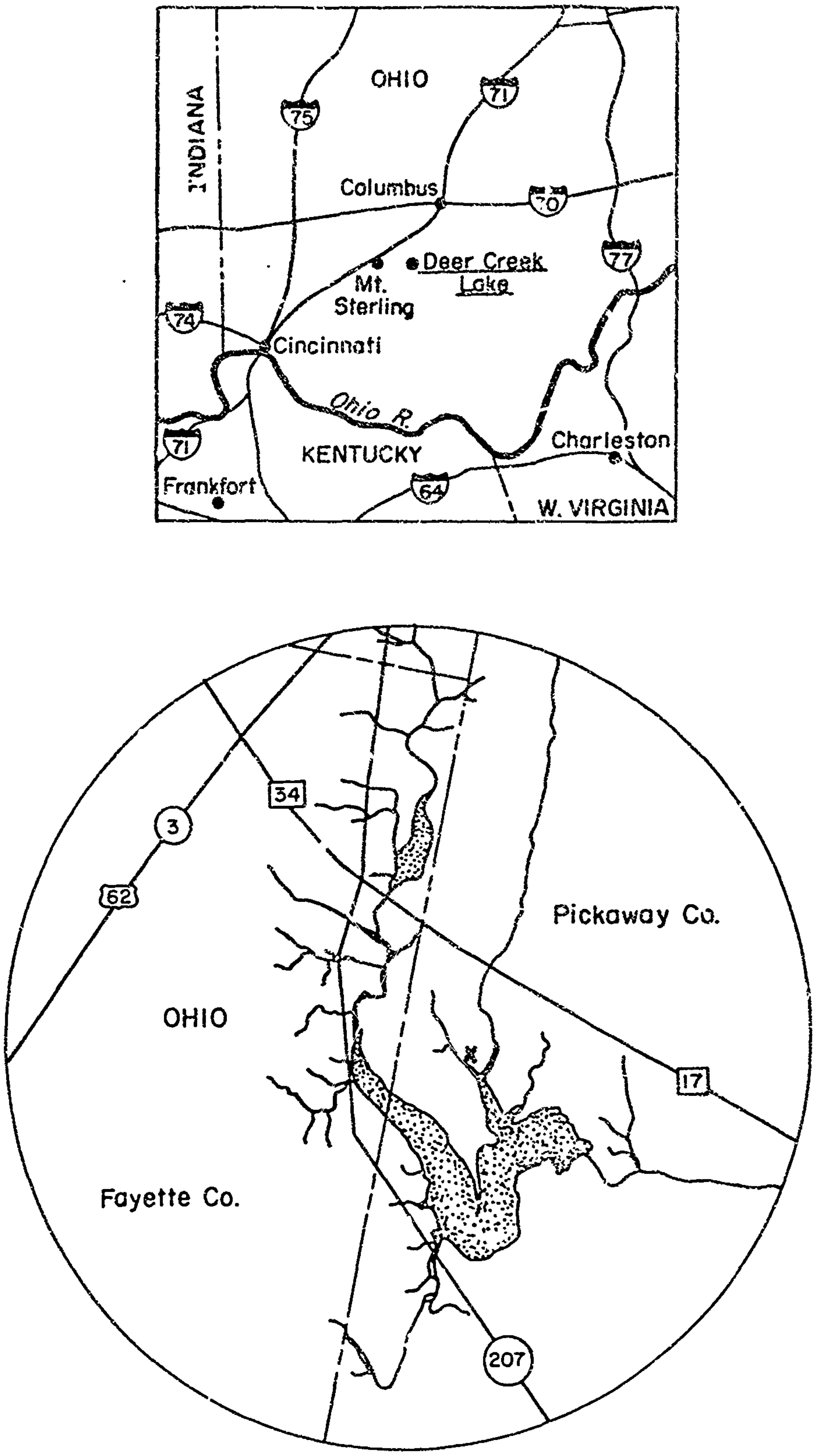


Figure 1. Site and vicinity maps, Deer Creek Lake State Park, Ohio.

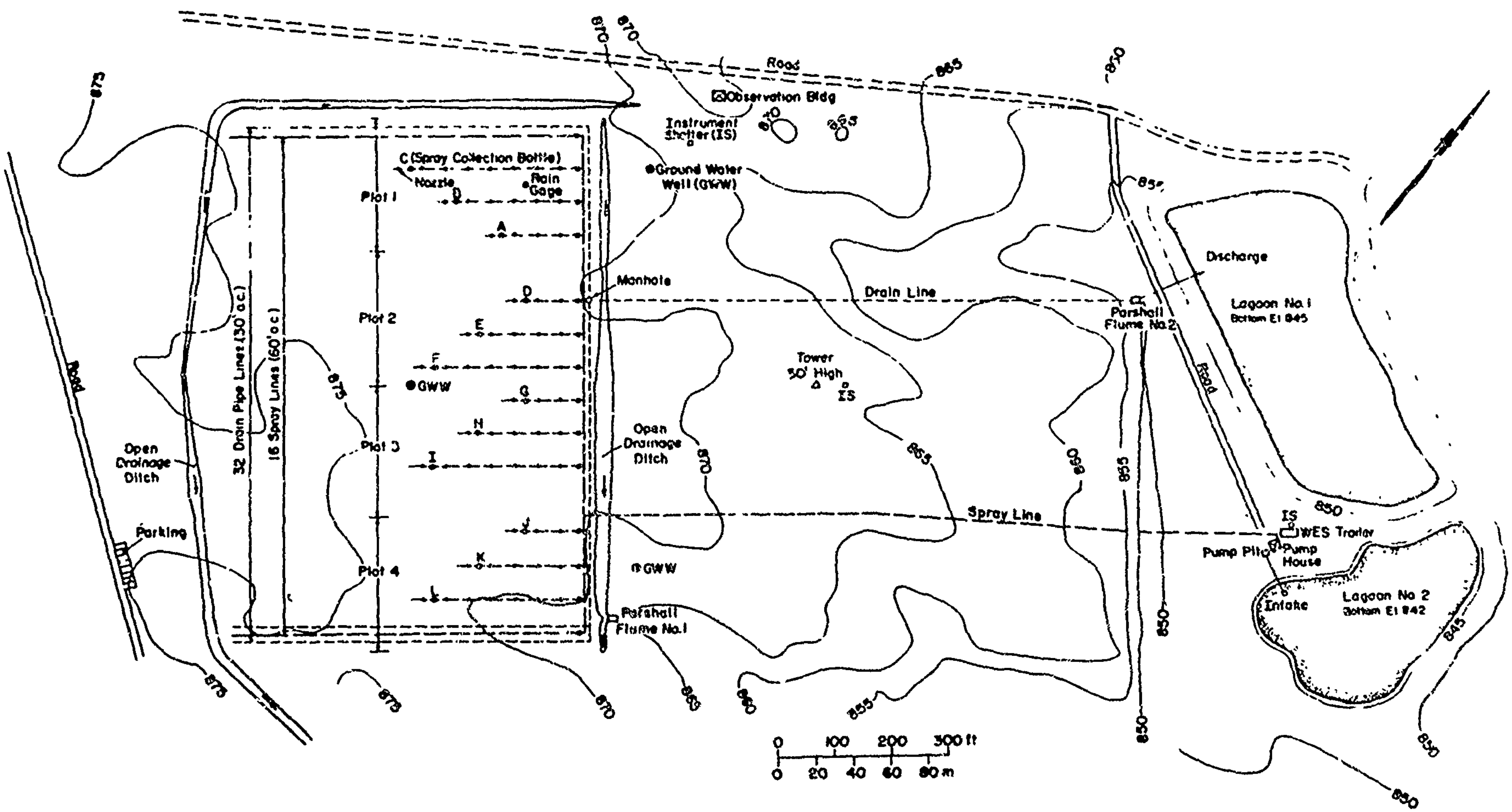


Figure 2. Layout of Deer Creek Lake Land Wastewater Treatment Project.

Site Preparation

USAMBRDL provided nearly all equipment and supplies for laboratory analyses including acquisition of both Andersen and Litton aerosol samplers. A mobile laboratory supplied by the Waterways Experiment Station had facilities to provide distilled water, gas, ultraviolet light, an autoclave and a controlled temperature environment. All laboratory analyses were conducted in the mobile laboratory r at Ohio State University. CRREL provided 9-m (30-ft) and 20-m (65-ft) high portable towers. The 9-m tower was used for elevated aerosol sampling (Fig. 3) and the 20-m tower for meteorological instrumentation.

A 112-V AC electrical powerline was extended to the sampling field, and a local electrician installed a dropline and two extension cords. The dropline was 207 m (680 ft) long, comprising three strands of 0 gage insulated wire with a #12 copper wire supplying the ground. At 30-m (100-ft) intervals along the dropline, double all-weather outlets were installed. The two extension cords were assembled in a "T" configuration, 30 and 60 m long. A #12 three-wire insulated copper cable was used for this purpose. Five all-weather outlet boxes were placed at intervals of 3 m to correspond with the position of the sampler stands at the 20 and 40-m downwind locations. Less than 5% reduction in current was measured along the dropline extension cord. Two gasoline engine-powered generators were rented to supply power to the upwind and at times to the 200-m sampler locations.

The spray fields are located over 300 m from the secondary holding pond (Fig. 2). To establish the time necessary to flush all the lines of residual water, a 5-min pulse of fluorescent dye was injected into the water line at the pump station, and grab samples were taken in the spray area at the nearest and most distant nozzles. The dye concentration in the samples was measured fluorimetrically to determine the time required for the dye pulse to course through the distribution system. Twenty-five minutes was established as an adequate length of time to flush the lines, ensuring that during a sampling period only fresh secondary wastewater from the holding pond was being applied to the spray area.

Climate

The climate of the area is that of a Midwestern temperate zone, continental type. Tropical air masses from the Gulf of Mexico often reach central Ohio during the summer. Consequently, summers are warm and humid with afternoon thunderstorms occurring frequently. Central Ohio does not normally have a "dry" or "wet" season, with precipitation being quite uniform throughout the year. The 30-year normal total precipitation from 1 July through 14 August (the study period) equals 160 mm (6.3 in.). During the six-week study period, 140 mm (5.6 in.) of rain occurred at the tower site and 152 mm (5.98 in.) at the lagoon site (Table A1). Both were slightly below the normal amounts expected in central Ohio.

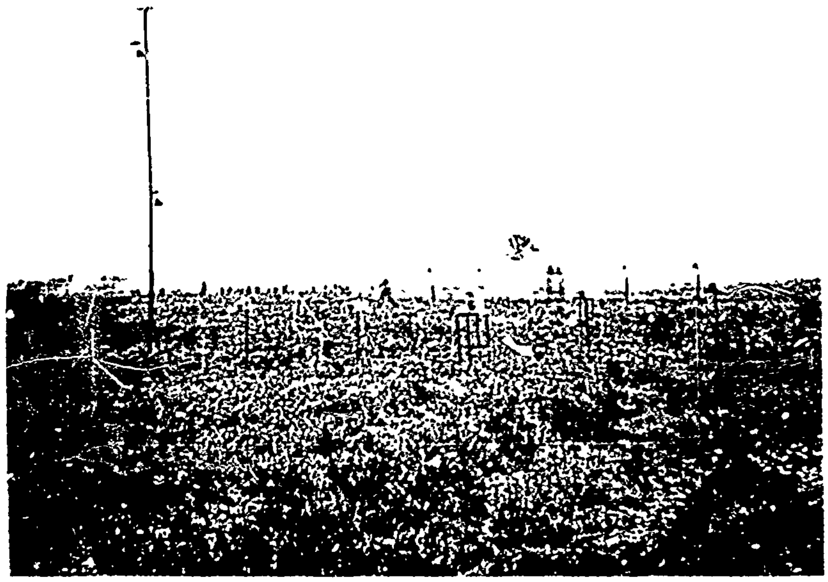


Figure 3. Samplers on 10-m tower

Average air temperatures for July and August (U.S. Department of Commerce 1975) are 23.1° and 22.2°C respectively. The area's normal average daily maximum temperatures are approximately 29°C, with the minimum averaging 16°C during the July to August time frame. During this study, air temperatures at the site averaged 2.2°C and 2.8°C colder than normal, respectively (Table A1).

Prevailing wind directions (Fig. 4) for the Deer Creek area are south-southwesterly during July, shifting to southwesterly by mid-August. Average long-term mean wind velocity for the two months is 2.7 m s^{-1} (6.1 mph) with gusts occasionally reaching 17.9 m s^{-1} (40 mph). These gusts usually occur during thundershowers or are associated with frontal activity. Wind directions were predominantly south-southwestly during the test period with a mean velocity of approximately 2.2 m s^{-1} (5 mph).

Meteorological Instrumentation and Measurements

CRREL, with assistance from the Atmospheric Sciences Laboratory (ASL) White Sands, New Mexico, provided meteorological instrumentation which included a 20-m (65-ft) tower, with lightning protection, and recording instrumentation for the following parameters: wind speed and direction, air temperature, relative humidity (RH), evaporation, precipitation, solar radiation and atmospheric pressure. Visual observations were made of sky conditions on a regular schedule and more frequently during sampling periods.

The meteorological instrumentation installation was completed on 2 July at three locations on site. These sites were located respectively between the two lagoons, at the tower and near the observation building (Fig. 2). The meteorological instruments installed at each site are listed in Table 1.

Table 1. Meteorological instrumentation.

Lagoon site (approximately 305 m from spray area)

Evaporation (class A pan)

Precipitation gage

Maximum and minimum thermometers

Hygrothermograph (continuous recording of temperature and relative humidity)

Tower Station (approximately 200 m from spray area, see Fig. 5)

Class A pan (water temp, maximum and minimum daily)

Precipitation gage (recording weighing type)

Instrument shelter ((maximum and minimum thermometers, hygrothermograph)

Anemometer at 2-m elevation (wind speed and direction recorders in observation building)

Anemometer, at 20-m height on tower (wind speed and direction recorders in observation building)

Hygrothermograph 15-m height (attached to tower)

Observation building (approximately 100 m from spray area, see Fig. 6)

Rain gage (digital readout in the instrument shelter)

Maximum and minimum thermometers, hygrothermograph

Anemometer at 2-m height (wind speed and direction recorders in observation building)

Microbarograph (recorder in observation building)

Solar instruments (vertical short wave incoming and reflected shortwave, both Epply instruments, one inverted for reflective radiation. Range of spectrum: ultraviolet through infrared, recorder installed in the observation building)

Rain gage (installed in the spray area recorder in the instrument shelter)

In addition to the above instrumentation, a precipitation or spray collection network was randomly placed in the spray fields to determine uniformity of the spray system. Locations of the 12 plastic 15-cm-diam, 30-cm-deep samplers are plotted in Figure 2 (A-L). A recording rain gage with a digital output was also installed in plot 1 to record both precipitation and spray volume. Water volume measurements were taken in plots 1 and 2 after each sample run. Measurements were terminated in plots 3 and 4 after 12 July. All water application data taken in the spray field area are presented in Table A4.

Daily evaporation was observed at the tower station and the lagoon site. These total evaporation values are presented in the Table A1.

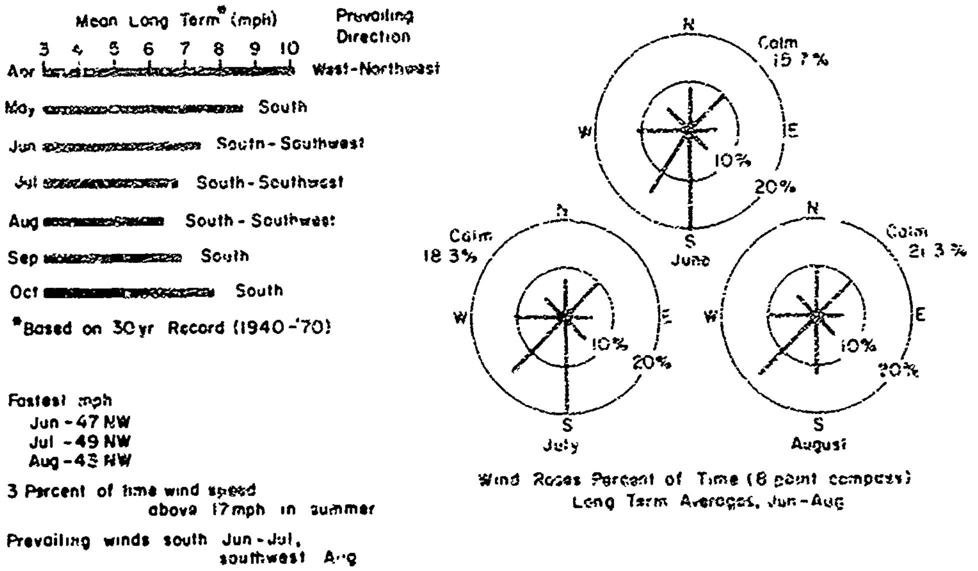


Figure 4. Long-term average, surface winds Columbus, Ohio- (Apr. - Oct.) (closest first order station having a long-term record of wind) 1 mph - 0.4 m/s.

Figure 5. Tower meteorological station.

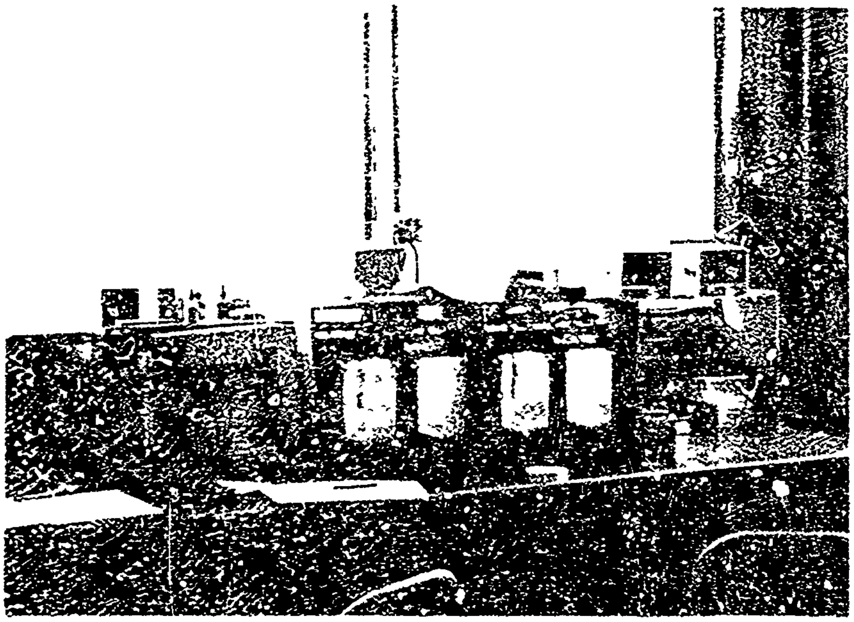


Figure 6. Wind and radiation recording equipment, observation building.

Atmospheric Stability Analysis

Ground-level concentrations of wastewater constituents that are experienced during aerosol spraying are a function of atmospheric stability. Stability classifications simply indicate the change of air temperature with increasing height.

For the maximum collection of released aerosols from spray heads 3 to 5 m above the ground surface at Deer Creek Lake, it was necessary to develop a method that would predict sampler placement in the field.

Meteorological parameters other than the temperature gradient that have an effect on surface released aerosols are wind, precipitation, humidity, solar radiation and cloud cover. Aerosol sampling runs at Deer Creek Lake were attempted under the most stable atmospheric conditions and were not initiated during periods of precipitation, shifting wind directions, or speeds above 7 m s^{-1} (15 mph).

For example, a sampling run was attempted under unstable conditions, just prior to a severe thunderstorm on the afternoon of 21 July but the run was aborted after 3 minutes because of heavy rain and shifting winds. Precipitation at the rain gage was measured at 10.2 mm (0.40 in.) during the storm. In the test field an average of 13.2 mm (0.52 in.) was recorded, showing the variability between gages only a short distance apart.

Atmospheric stability was determined for each test run according to basic procedures used in making plume dispersion estimates as suggested by Turner (1970) and Pasquill (1961). Using these reports, equations for predicting plume dispersion concentrations of air pollutants were developed. These gave a first approximation for the placement of the tower and downwind aerosol samplers (see *Results: Meteorology*). However, in the present case the spray height did not exceed 3 to 5 m, whereas Turner developed his curves for sources hundreds of meters in height.

Considering the spray field as more closely related to a line source than a point source, the applicable equation taken from Turner (1970) is

$$\chi(x,0,0,H) = \frac{Q}{\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \tag{1}$$

where: χ = concentration (g m^{-3})

Q = the uniform emission rate of particles (g s^{-1})

u = the average wind speed (m s^{-1})

H = the height of plume centerline (m); in this case the mean spray height was estimated to equal 3.05 m (10 ft)

σ_y, σ_z = standard deviations of plume concentrations in the horizontal and vertical directions, respectively (m)

x = the distance from the source (km).

It is necessary to find χ for H = 3.05 m (10 ft) when x = 0.1; 0.2, and 0.3 km, and u = 2 to 6 m s^{-1}. (The appropriate σ's are obtained from Turner 1970, Table 3-1, modified below, and Fig. 3.2 and 3.3). Values for σ_y and σ_z have been selected below according to the expected wind speed.

Class A is the most unstable condition, and class D is the most stable condition considered here and would be assumed to occur at night regardless of wind speed (see Table 2).

Table 2. Key to stability categories.

Wind speed at 2 m ($m\ s^{-1}$)	Incoming Solar Radiation: Clear (strong)	Partly cloudy (moderate)	Overcast (slight)
2	A	A-B	B
3	A-B	B	C
4	B	B-C	C
5	B-C	C-D	D
6	C	D	D

When two applicable stability types occur in Table 2 above, the resulting means are used. The equation was normalized to give the particulate concentration per emission rate, i.e.:

$$\frac{\chi}{Q} = \frac{\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]}{\pi\sigma_y\sigma_z u} = \frac{\exp\left[-\frac{1}{2}\left(\frac{3.05}{\sigma_z}\right)^2\right]}{\pi\sigma_y\sigma_z u} \quad (2)$$

Concentration rates are given in Table 3 for χ/Q in terms of ug m^{-3} g^{-1} s^{-1}. These values were then plotted in Figures 7 - 9 for field use giving an estimation of optimal placement of samplers for maximum collection efficiency.

Table 3. Predicted particulate concentation ($\mu g\ m^{-3} g^{-1} s^{-1}$), distance of sampler downwind from spray area, and intensity of solar radiation

$u(m\ s^{-1})$	Distance - 0.1 km			Distance - 0.2 km			Distance - 0.3 km		
	(strong)	(moderate)	(slight)	(strong)	(moderate)	(slight)	(strong)	(moderate)	(slight)
2	410	530	730	110	150	210	50	70	100
3	360	490	1020	100	140	310	40	70	150
4	370	510	760	110	150	230	50	60	110
5	410	890	1360	120	290	460	50	140	230
6	510	1130	1130	150	380	380	70	190	190

By comparing the above predicted concentrations with temperature gradients, solar gradients, solar radiation data, wind speed, and cloud cover, a stability class determination has been made for each of the 25 test runs.

Field Procedures and Sampler Positioning

The field setup comprised six interacting stations: laboratory, meteorological, and four field sampling positions. The four sampling sites were one upwind (background aerosol) and three downwind positions: 1) near (21 or 30 m), 2) intermediate (41 or 50 m), and 3) 200 m. Downwind distances were measured from the nearest (downwind) sprinklers. To ensure efficient operating procedures, the operator at each station was assigned individual responsibilities. The decision to initiate and/or abort a run, collection of composite effluent samples and coordination with the laboratory were assigned to the operator of the near station.

All samplers at the near and intermediate stations were activated simultaneously by switches in the observation building. Using radio communication, the operators manning the upwind and 200 m stations initiated and terminated their samplers within seconds of the recorded times. Radio monitoring and communications by the laboratory personnel allowed efficient preparation and operation, especially when weather conditions permitted more than one run per day.

Aerosol sampling was conducted when the wind velocity was less than 6.7 $m\ s^{-1}$ (15 mph) and wind direction was southwest to south. When a stable wind direction persisted, a 30-minute average of wind direction was recorded. With a Brunton Compass, a line was shot perpendicularly to the average wind direction bisecting the spray for sampler positioning (Fig. 10).

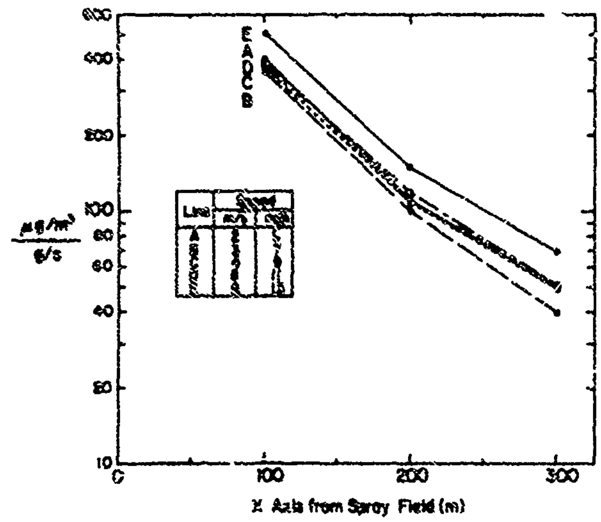


Figure 7. Predicted aerosol concentrations (strong solar radiation, various wind speeds and distances downwind).

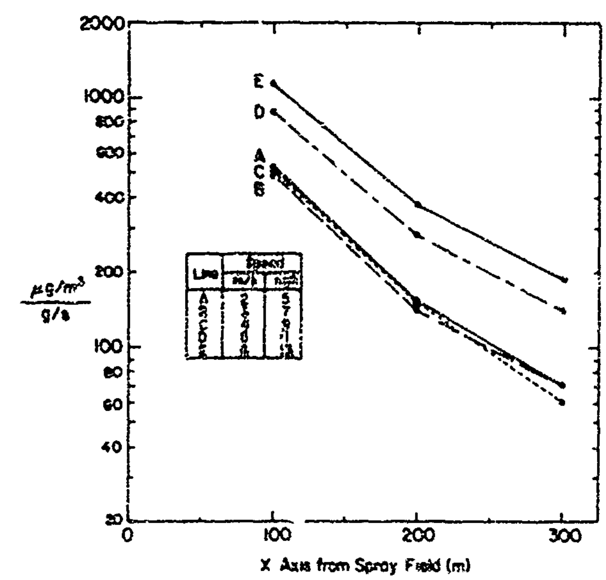


Figure 8. Predicted aerosol concentrations (moderate solar radiation, various wind speeds and distances downwind).

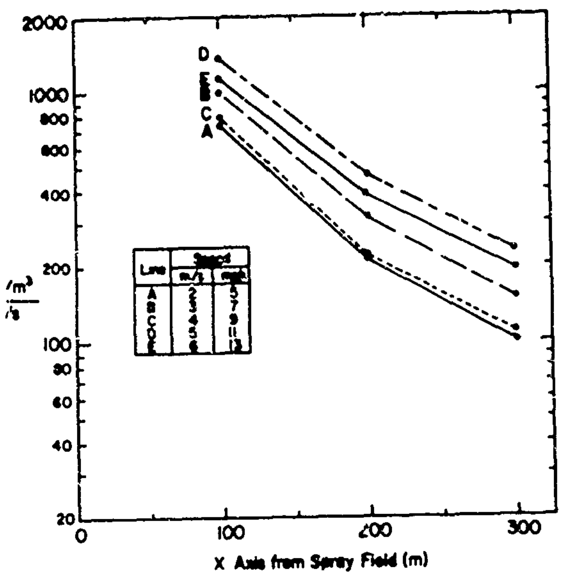


Figure 9. Predicted aerosol concentrations (slight solar radiation, various wind speeds and distances downwind).

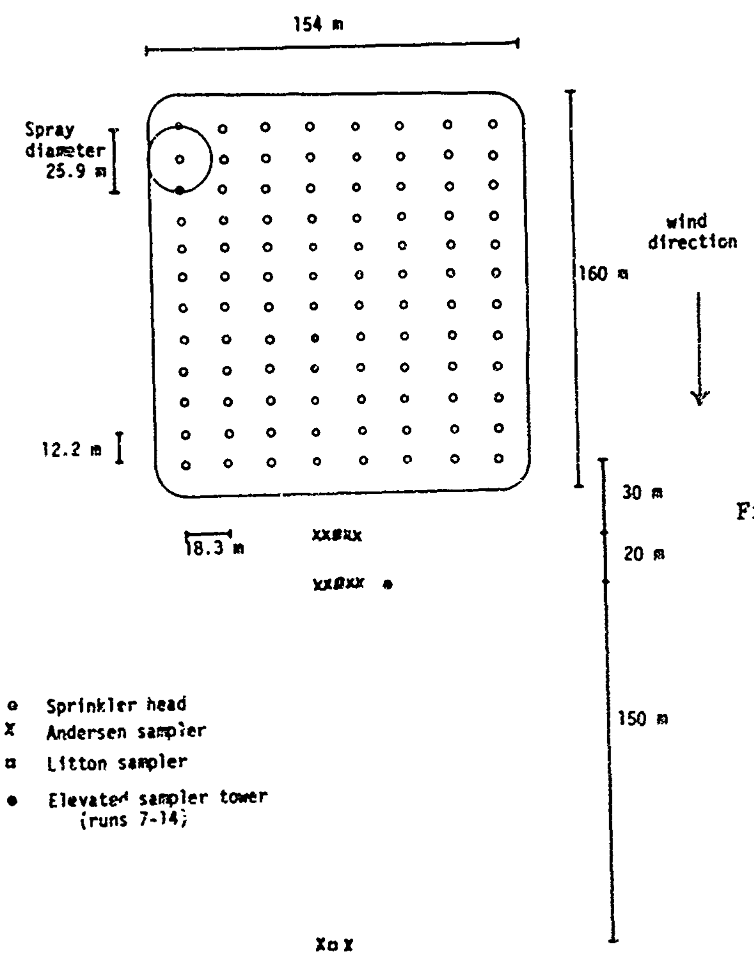


Figure 10. Typical downwind sampler array and spatial relation of operating spray heads.

During each run real time wind parameters were communicated every two minutes to the operator at the near site by the meteorological specialist. The meteorological specialist also initiated each run by switching on the power to the dropline, timed the run for 20 minutes and terminated it. For consistent testing, any sampling run was aborted if the wind direction shifted more than 90° before 15 minutes of sampling time had elapsed.

The first or near row of aerosol samplers was positioned 21 or 30 m from the most downwind row of sprinkler heads, with actual placement being governed by topographic features. The second or intermediate row of samplers was always located 20 m downwind of the first row. All samplers were aligned perpendicularly to the prevailing wind direction, elevated on 1.7-m-high stands and set 3 m apart. Each of these rows contained a total of five samplers: a Litton sampler (Fig. 11) placed in the center of each row, flanked at the 3-m intervals by either four Andersen (microbiological runs) or four all-glass impinger (AGI, dye run) samplers. Two Andersen or AGI samplers were stationed upwind and two at the 200-m or the elevated downwind site. To attain a vertical aerosol profile during runs 7-14, two small samplers were raised to 4.6 and 9-m elevations on a tower located at one end of the 50-m downwind sampler row. In runs 1-6 and 15-25 two small samplers were located 200 m downwind (Table 4). The upwind sampler station, used to provide background information, consisted of two small samplers and a Litton sampler. A typical sampler array is illustrated in Figure 10. Occasionally terrain features prevented positioning a row of samplers at the prescribed distances from the spray heads. When this occurred, they were uniformly moved farther away, always maintaining 3-m centers.

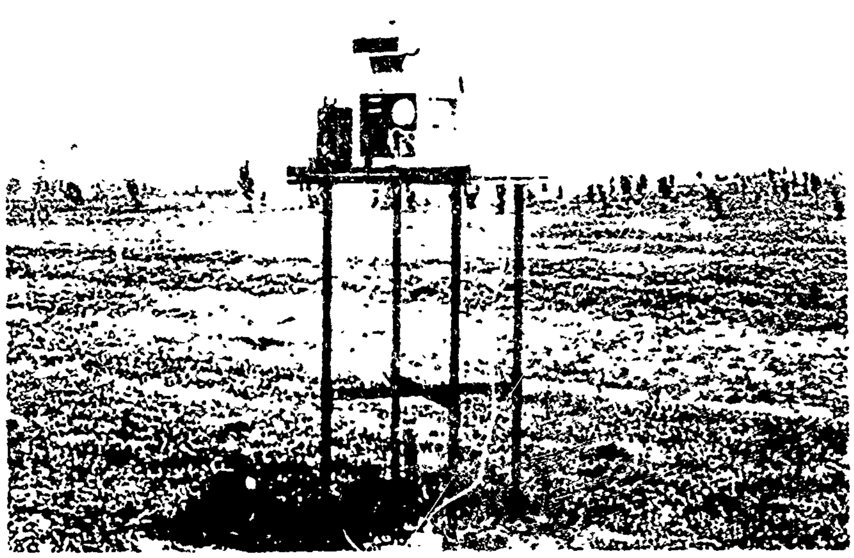


Figure 11. Litton High-Volume Sampler Model M (electrostatic precipitator).

TABLE 4. Locations of samplers during aerosol studies, Deer Creek, Ohio -- summer 1976.

DATE/RUN		ANDERSEN OR AGI SAMPLERS												LITTON SAMPLINGS					REMARKS
		1	2	3	4	5	6	7	8	9	10	11	12	A	B	C	D	E	
14 Jul 76	1	U	41*	41	21	21	21	21	U	41	41	200	200	21	200	41	U		All runs bacteriological unless
"	2	U†	41	41	21	21	21	21	U†	41	41	200	200	21	200	41	U†		unless otherwise indicated
15 Jul 76	3	21	41	41	21	21	41	41	U	U	200	21	200		21	41			
"	4	21	41	41	21	21	41	41	U	U	200	21	200		21	41			
17 Jul 76	5	U	21	U		200		21			41	41	200		41	21			
"	6	U	21	U		200		21			41	41	200		41	21			Dye Run
20 Jul 76	7	U	30	50††	30	50	30	U	50	50	30	50	50**		50	30	U		
"	8	U	30	50††	30	50	30	U	50	50	30	50	50**		50	30	U		
"	9	U	30	50††	30	50	30	U	50	50	30	50	50**		50	30	U		Dye Run
21 Jul 76	10	U	30	50	30	50	50	30	50††	50	30	30	50**		30	50	U		
28 Jul 76	11	30	30	50	30	30	U	50	U	50	50††	50	50**		U	50	30		
"	12	30	30	50	30	30	U	50	U	50	50††	50	50**		U	50	30		
"	13	30	30	50	30	30	U	50	U	50	50††	50	50**		U	50	30		
29 Jul 76	14	30	U	30	30	30	50	U	50††	50	50	50	50**		30	U	50		
"	15	30	U	30	30	30	50	U	200	50	50	50	200		30	U	50		Sampler 3, 6 & 12 fell off
5 Aug 76	16	50	30	U	30	50	50	200	30	200	30	U	50		50	30	U		stands during run
"	17	50	30	U	30	50	50	200	30	200	30	U	50		50	30	U		
"	18	50	30	U	30	50	50	200	30	200	30	U	50		50	30	U		Dye Run; B failed during run
"	19	50	30	U	30	50	50	200	30	200	30	U	50		50	30	U		Night run
10 Aug 76	20	30	30	50	U	50	30	50	200	50	U	30	200		U	50	30		
11 Aug 76	21	200	50	30	30	U	50	200	U	50	30	30	50		U	50	30		
12 Aug 76	22	U	30	50	50	30	50	30	30	50	200	200	U		50	U	30		
"	23	U	20	40	40	20	40	20	20	40	200	200	U		40	U	20		Dye Run
"	24	U	30	50	50	30	50	30	30	50	200	200	U		50	U	30		
"	25	U	30	50	50	30	50	30	30	50	200	200	U		50	U	30		

U = Upwind

All runs within any given day were set up in the same sequence; a new day = a new set-up sequence. Only 3 days had a single run; all others, multiple runs.

*Distances in meters from the downwind edge of spray area. All samplers operated 20 minutes unless otherwise specified.

**Sampler at 9-m elevation

†Ran 25 min.

††Sampler at 4.5-m elevation

Airborne bacteria were collected by both Andersen viable-type stacked-sieve samplers loaded with *Standard Methods* agar (Baltimore Biological Laboratories) in disposable plastic petri dishes, and high-volume electrostatic precipitator samplers (Litton Model M) through which 100 ml of 1/2-strength Plate Count Broth (Difco) was continuously recirculated at 10-12 ml/min. Airflow through Andersen samplers was regulated at 28.3 liters/min by critical orifice. Litton samplers were operated at 1000 liters/min and at an electrostatic potential of 13 to 14 kV.

The Litton samplers were labeled A through D (A was used for the first two runs only). The Andersen and AGI samplers were labeled 1-12 as were the piston, diaphragm-type air vacuum pumps used to draw air through the samplers. Throughout the study each sampling unit, comprising the sampler, tubing, pump and critical orifice, was kept together to provide comparison of data quality. The positions of the sampling units were rotated each sample day (Table 4) as prescribed by a random distribution chart.

Before the Litton samplers were transferred to the field they were checked for mechanical problems, and the rotating disk was cleaned with either Alconox and sterile distilled water or 0.1% Clorox, pH 6-6.5. The Clorox solution was then pumped through the entire liquid system. To neutralize the Clorox, 1% sterile sodium thiosulfate was pumped through the system, and finally the sampler was flushed with 50 ml of sterile distilled water. The sample collection plate was occasionally wiped with Alconox and rinsed with sterile water to remove the film that built up from the plate count broth. When more than one run was conducted per day, the sterilization process was done in the field between runs.

After each sterilization procedure, a zero time sample was taken just prior to a run by pumping sterile half-strength plate count broth through the sampler, and collecting 5 ml in a sterile test tube. Care was taken to handle the inlet and outlet tubing aseptically. This zero sample was stored in a covered ice bath until delivery to the laboratory. At this time the Andersen samplers (sterile, loaded and capped) were transported to the field. The Andersen samplers were placed atop the stands and matched by number to the previously positioned pumps. At the beginning of each run day the Andersen samplers were steam-sterilized in the autoclave. If two or more runs occurred in one day the samplers were cleaned with 70% Isopropanol between runs. This procedure was discontinued after the first 8 runs because time did not allow for sterilization of the Andersen samplers between runs. Therefore, during subsequent runs aseptic precautions were taken in handling the exposed plates and insertion of sterile plates for the second run.

Before each run, the Andersen samplers were connected to the flow pumps, all caps and covers were removed from sample intakes on both Andersen and Litton samplers and the Litton power switches were turned on. When the main power was switched on, the prescribed air flow rate, high voltage setting and liquid flow rate on the Litton samplers were adjusted, and all Andersen vacuum pumps were checked.

Before initiating a run a radio check was made with each station, and the generators at the upwind and the 200-m stations were started. The timing control was turned over to the meteorological specialist who activated the 21- and 41-m samplers. The upwind and 200-m stations were instructed simultaneously via radio to initiate testing. During the microbiological runs the operator at the 20-m station would collect a 750 ml composite sample of the effluent, taking 150 ml every 4 minutes. At the end of the run the inlet tubing of the Litton samplers was aseptically removed from the collection fluid and the power turned back on, allowing the liquid to be pumped into the sample bottle until all residual plate count broth was removed from the sampler. The exposed broth was capped and placed in a covered ice bath. Samples were immediately transferred to the laboratory for analysis.

LABORATORY PROCEDURES

Microbiology

The 12 Andersen samplers were of the stacked-sieve, viable type, each sampler having six sieves. Therefore, a total of 72 sterile, dry Andersen plates were required for each run. Sterile, disposable 100-x 15-mm plastic petri plates (Falcon 1029) containing 4?.0 ml of sterile SMA (*Standard Methods* agar, a peptone yeast extract-glucose medium, APHA 1971) were used. The volume of agar in these plates allowed about 2.5-mm clearance between the agar surface and the base of each sieve; this clearance permitted impaction of the bacteria in the aerosol sample onto the agar surface. The Andersen plates were first stored at room temperature for 1-2 days after preparation and examined for growth of bacterial contaminants and then stored at 4°C. Just prior to use, the plates were placed at room temperature storage to dry the agar surfaces. The Andersen plates were inverted and immediately placed in a dry 35°C incubator for 48 hours upon retrieval from the field.

Estimation of Standard Plate Count and Aerosol Particle Sizes

Estimation of numbers of colony-forming particles impacting on each Andersen sampler plate was accomplished by counting positive positions and applying a positive-hole correction as described by Andersen (1958).

From each Andersen sample, a median particle diameter was derived using the relation shown in Figure 12 (Dimmick and Akers 1969). The median diameter is the diameter corresponding to the number of stages, counting from the top, that cumulatively bear 50% of the sample. Similarly upper and lower quartile diameters were estimated by using the number of stages cumulatively bearing 25% and 75% of the sample, respectively.

An estimate was made of the percentage of each sample falling within the range 1.0 to 5.0 μm, as this has been shown to be the range of efficient deposition in human pulmonary alveoli. Using the curve shown in Figure 12, the fraction of a sample within this range is identified by excluding the two uppermost stages and stage 6 (Fig. 13).

High volume air sampling utilized 1/2-strength Plate Count Broth, which was pumped over the sample collection disks of the Litton samplers. The collection fluid also served as a bacteriological holding medium, and the bottle containing the exposed medium was placed in ice and shielded from light following completion of each run. The composite wastewater samples collected from the spray head during runs were also stored in ice; each grab sample was added to the large composite flask that was kept in the ice bath. SMA was used in duplicate plates for all standard plate count determinations performed on the Litton and composite grab samples. The spread plate method was used except for 1.0-ml and 10-ml volumes, for which pour plates were prepared. Incubation was at 35°C for 48 hours.

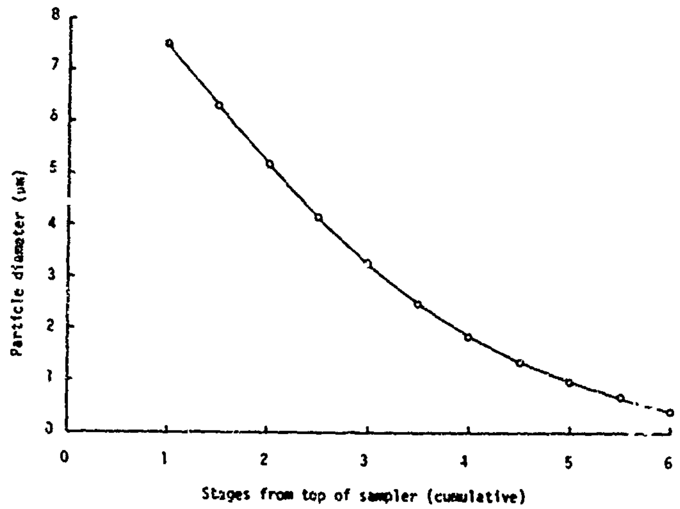
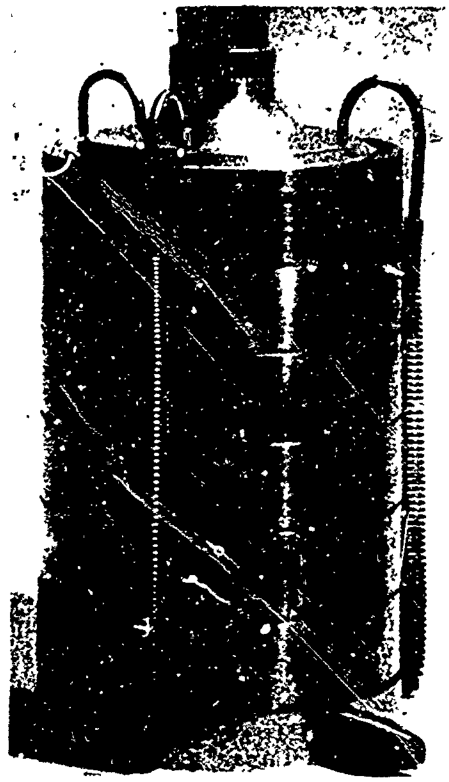


Figure 12. Relation of particle diameter to cumulative number of stages from top of Andersen sampler.

Estimation of Other Bacteria

Though the standard plate count was chosen as the microbiological parameter to receive greatest emphasis, measurements of other bacterial parameters and coliphage were also performed. Total and fecal coliform and fecal streptococcus levels in composited wastewater samples were estimated by the Millipore membrane filter method by using m-Endo(Difco Laboratories) and m-FC(Baltimore Biological Laboratories) broths and m-Enterococcus agar, respectively, utilizing *Standard Methods* (APHA 1971). The total coliforms were incubated at 35°C for 22-24 hours, fecal streptococcus for 48 hours, and fecal coliforms in a 44.5°C water bath for 22-24 hours. When several runs occurred in one day, membrane filter samples were iced so that all runs could be assayed together. Data on fecal coliform and fecal streptococcus in effluent to be sprayed were also obtained from the Department of Agronomy, Ohio State University.



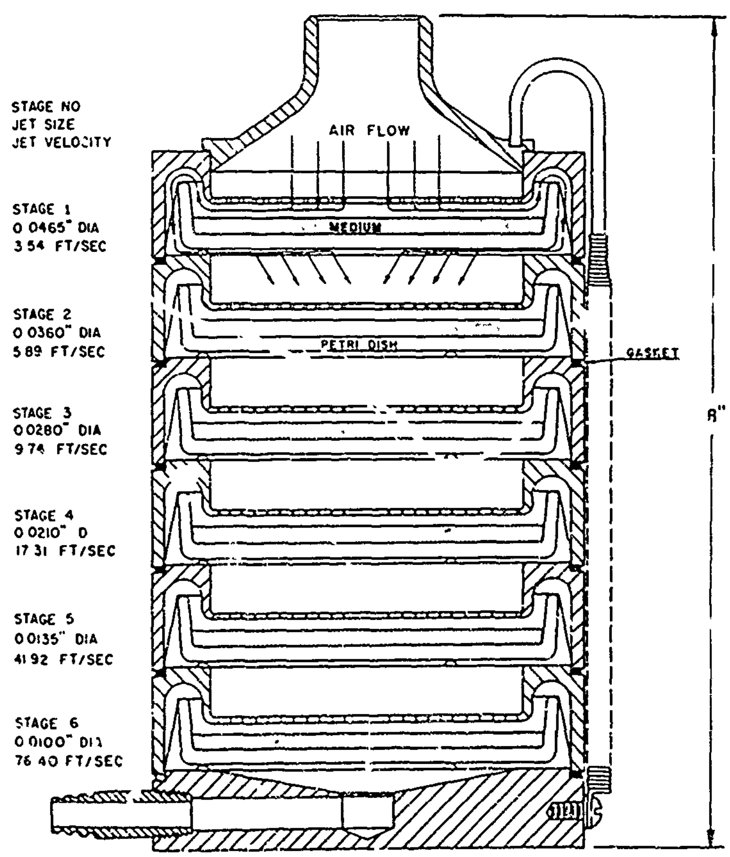


Figure 13. External view and longitudinal section of six-stage Andersen viable type sampler.

Fifty-six bacterial isolates obtained from wastewater grab samples and 44 from aerosol samples were picked as random colonies on plates of SMA and purified for identification. The aerosol-derived isolates were taken from Andersen samplers at near (20-30 m) and intermediate (40-50 m) distances downwind in each of three runs. Grab sample wastewater isolates were taken from the same three runs. All colonies appearing on a given plate or a quadrant of a plate were included in the samples to preclude bias based on colony morphology. In addition, approximately equal representation was afforded the various stages of each Andersen sampler.

A number of biochemical and growth response tests allowed classification into a number of somewhat arbitrary response groups. The schema followed is shown in Figure 14.

On two separate occasions, 6-liter samples were collected at the spray nozzle, packed in ice and sent to the Center for Applied Research and Technology at the University of Texas at San Antonio for bacterial and viral assessment. Bacterial colonies growing on a general purpose medium were chosen, tested and identified. Enteroviruses were sought by concentration followed by both 3-day and 5-day incubation on HeLa cell cultures. The concentration method is capable of detecting virus at a level of approximately 1.0 PFU/ℓ (plaque-forming units/liter).

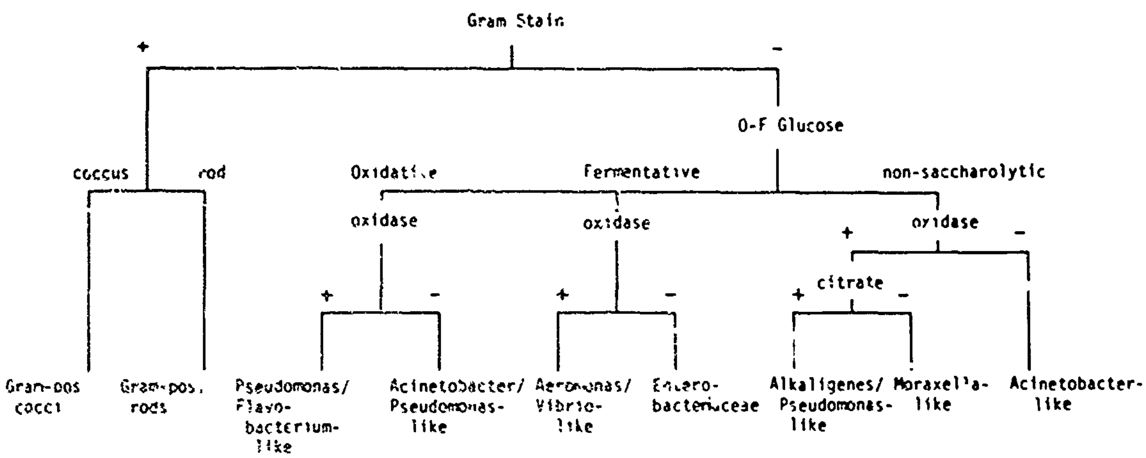


Figure 14. Schema for the assignment of bacterial isolates into arbitrary groupings.

A random sample of 57 presumptive coliforms from nozzle grab samples, identified by the membrane filter method on m-Endo broth, were tested for gas production in lauryl tryptose lactose broth by the Durham tube method. They were scored as confirmed or unconfirmed coliforms on this basis, together with their appearance on Eosin Methylene Blue agar. All isolates were further tested on the r/b multi-test system (Diagnostics Research Inc.) for identification as to probable genus or species. This system is adapted primarily for identification of members of the family *Enterobacteriaceae*.

Estimation of Coliphage

Both Litton and composite spray samples were randomly assayed for indigenous coliphages, using five different strains of *Escherichia coli*: K-13, 25922, C-3000, B and 162. Tryptone Yeast Extract (TYE) and Phage Assay Broth agar (PAB) pour plates containing 20 ml/plate were overlaid with 2.5 ml of soft TYE or PAB agar respectively containing both 1.0 ml of sample and 4 drops of one of the above organisms in logarithmic growth phase broth culture. These plates were then incubated at 35°C for about 8 hours and inspected for coliphage plaques. Influent sewage samples from the trailer dump station at the campground as well as from the primary stabilization pond were run as positive controls to be sure that the coliphage assay system was working properly.

Fluorescein Dye Runs

Disodium fluorescein (Fisher uranine) solution, 5% in distilled water, was injected at the irrigation system pump pit into the spray line leading to the field (Fig. 2). A constant injection rate of 100 ml/min was maintained through use of a peristaltic pump. Air sampling for recovery of fluorescein aerosol was delayed for an interval of time as determined by prior experimentation, as previously described. This delay allowed the dye to reach the most distant spray heads and to optimize dye aerosol distribution throughout the field. During dye runs, Andersen samplers were replaced by AGI's.

Prior to usage, 35 ml of distilled deionized water was dispensed into thoroughly cleaned AGI's. This volume was shaken, and 5 ml was transferred to a similarly treated test tube as a pre-exposure blank. These blanks were measured on the Perkin-Elmer Model 204 Fluorescence Spectrophotometer to ensure that none of the water in the AGI's fluoresced. An identical blank check was performed on the Litton sample bottles containing 100 ml of distilled deionized water. The actual dye aerosol sampling procedures were identical to those for the microbiological runs, as described in the previous section. During fluorescein tracer runs, grab samples were taken at the spray nozzle at 2- to 3-minute intervals. These were not pooled to permit a check on possible fluctuations in fluorescein level during the injection period. Following the run all samples were assayed fluorometrically against known sodium fluorescein standards. All the assays were performed by one individual throughout the study to ensure maximum consistency and repetition of procedure. Four dye runs were performed: runs 6, 9, 18 and 23 (Table 4).

Chemical, Physical and Wastewater Parameters

Wastewater samples taken at the intake of the second lagoon (Fig. 2), were tested by personnel of Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi, for the following parameters (samples were taken simultaneously with aerosol test runs):

1) hardness

2) chemical oxygen demand (COD)

3) total organic carbon (TOC)

4) total chlorine and

5) free chlorine.

The procedures in *Standard Methods* (APHA 1971) were followed in performance of all tests. COD samples were preserved by addition of H_2SO_4 and refrigeration, hardness samples by refrigeration, and TOC samples by addition of HCl and freezing. Free and total chlorine determinations were performed using the ortho-tolidine (Hach) method.

Additional physical and chemical wastewater parameters were measured at the Department of Agronomy, Ohio State University. These are given in the Tables A5-A7, and include pH, biochemical oxygen demand, hardness, phosphorus, nitrogen, chloride and total and dissolved solids.

Quality Assurance

Variability in aerosol collection efficiency among air samplers or sampler-pump combinations was determined by laboratory tests. Four to six Andersen Samplers or AGI samplers were placed side-by-side in a 980-liter plexiglass chamber. AGI samplers were tested using dye aerosols generated from a 0.5% sodium fluorescein solution. The samplers contained 30 ml of distilled water, and operation time was 8 to 10 minutes. Andersen samplers, which were operated for 20 minutes, contained SMA and were tested using aerosols generated from secondarily treated sewage (bio-disk) obtained from the USAMBRDL pilot sewage treatment plant. Alternatively, an aerosol generated from a mixture of *E. coli* strain 162 and *Serratia marcescens* suspended in dilute phosphate-buffered saline (500 ppm total solids) was used. These organisms were maintained on nutrient agar (Difco) slants and were taken from fresh 16-hour 35°C shake cultures in plate count broth. These samplers were operated for 20 minutes. In both cases, aerosols were generated from an aqueous solution or suspension by a spinning-disk aerosol generator (Environmental Research Corporation Model 8330).

At the test site, laboratory analytical procedures were at times performed simultaneously by both an experienced and an inexperienced person using the same samples. This was done particularly in early phases of the study. Special emphasis was placed on the counting and interpretation of bacterial colonies on pour plates and streak plates used in coliform assessment, enumeration of positive positions on Andersen sampler plates, coliphage plating and plaque identification, and fluorescent dye determinations. Sufficient replicate testing and counting were performed to assure adequacy and uniformity of all testing procedures and results.

RESULTS

Meteorology

The climatic conditions at the Deer Creek Lake site during the test period averaged nearly normal from 1 July - 17 August. Air temperatures averaged 2.1°C below normal and prevailing wind directions from the south-southwest had an average velocity of 2 m s^{-1} (5 mph). The prevailing direction is important for installation of aerosol collectors, as they were installed directly downwind of the spray heads for maximum collection during test runs.

Daily meteorological measurements for the period 1 July -14 August 1976 are summarized in Table A1. The detailed measurements taken during each aerosol sampling period are presented in Tables A2 and A3 in Appendix A. Minute-by-minute wind speed and direction were systematically recorded during test runs to determine variability, if any, during sampling. These minute-by-minute winds are not presented in this report;

however, they are available from CRREL on request. The wind data presented in Table A3 represent the average for a run time of approximately 20 minutes.

Figures 7-9 and Table 3 give predicted concentration values of aerosols at 100, 200, and 300 m downwind of the spray field. Using Table 3 it was decided prior to any testing to place the meteorological tower and main meteorological site 200 m downwind from the spray field. This determination was made by comparing the predicted values obtained at 100 m to those at 200 m. These data show an average predicted 67% aerosol concentration loss between 100 and 200 m. However, most samples were taken within the first 50 m downwind from the spray nozzles (Fig. 10) for maximum aerosol collection.

By using Table 3 and considering temperature gradients up to the 15-m level on the tower, a stability class determination was made for each of the 25 test runs. Stability determinations (A-D) are included in Table A2. The meteorological data in the Tables A1-A3, when analyzed, show that in most cases the test runs were made under stable atmospheric conditions (i.e. wind speeds < 6 m s^{-1}, partly cloudy skies, slight or nonexistent temperature gradients for the first 15 m aloft, no rain, and average incoming solar radiation and evaporation). Near the tower station the total evaporation for the six-week period was 292 mm (11.1 in.) and at the lagoon site 277 mm (19.9 in.). Evaporation can be considered an indicator of stability, as a high evaporation day is normally a day with few clouds, moderate wind velocities, and high incoming solar radiation. Incoming solar radiation averaged approximately 500 langleys/day for the test period (Table A1). The above values for evaporation and incoming solar radiation are close to those expected for Ohio in the summer season. Test runs 3, 6, 21, and 24 were attempted under less stable conditions and show lower aerosol concentration at the samplers.

Further analysis of prediction (or development of a model for determination) of aerosol concentrations vs the field measured strength of aerosols at various distances downwind under known atmospheric stability will not be presented in this report. This work has been performed under contract by H.E. Cramer Inc., Salt Lake City, Utah (Dumbauld et al., 1978).

Wastewater Characterization

Chemical and Physical

Measurements of physical and chemical wastewater parameters made at the Department of Agronomy, Ohio State University, are presented in Tables A5 and A6; summary values are given in Table A7. These measurements were made on samples from the point at which water leaves the second lagoon for the spray field.

Total residual chlorine levels in water used for spraying (measured daily) ranged from 0.1 to 0.4 mg/l. No free chlorine was detected. The water was moderate in hardness, 163-198 mg/l, and alkaline, pH 7.0-8.7.

Microbiological

Standard bacterial plate counts and levels of indicator bacteria, measured in sprinkler head grab samples taken during each run, are shown in Table 5. Standard plate counts varied from 5.8×10^3 to 6.6×10^4/ml with median of 2.9×10^4/ml. Total coliforms exceeded fecal coliforms by more than two orders of magnitude.

Table 5. Bacteriological determinations on wastewater in nozzle grab samples.

Run	Colony forming units/ml source: Total aerobic	Total coliforms	Fecal coliforms	Fecal streptococcus	Ratio FC/FS
1	5.3×10^4				
2	1.7×10^4				
3	3.6×10^4				
4	2.9×10^4				
5		25	0.5		
7	3.4×10^4	180	0.4	0.4	1.0
8	3.5×10^4	295	0.3	0.04	7.5
10	5.8×10^4	270	0.2	0.10	2.0
11	9.0×10^3	670	1.0	4.1	0.24
12	1.5×10^4	160	1.1	3.9	0.28
13	9.0×10^3	180	0.6	4.0	0.15
14	3.5×10^4	190	1.0	2.3	0.43
15	3.5×10^4	140	0.6	1.4	0.43
16	1.8×10^4	49	0.5	0.05	10.0
17	1.7×10^4	29	0.7	<0.05	-
19	8.0×10^3				
20	3.1×10^4				
21	2.8×10^4		<0.05	<0.05	-
22	2.1×10^4	35		<0.05	
24	6.6×10^4				
25	2.9×10^4				
Median	2.90×10^4	180	0.05	0.25	0.43

Mean = 2.20

Data on fecal coliform and fecal streptococcus obtained from Ohio State University are included in Table A5. These estimates are not based on the same samples as ours; thus they are not comparable on an individual basis. Considered as a group, the fecal coliform estimates, however, are in good agreement. The streptococcus counts, though quite variable, tended to be somewhat higher in the Ohio State results.

Results of further testing of a sample of 57 presumptive coliforms derived from nozzle grab samples are presented in Table 6. Though most were tentatively identified as *E. coli*, only about 50% were confirmed as coliforms.

Scoring of sprinkler-head grab samples by the center for Applied Research and Technology, University of Texas at San Antonio, showed 77%

Table 6. Results of confirmed coliform test, and most probable identification by r/b multi-test system, for 57 presumptive coliform isolates from nozzle grab samples.

Number passing confirmed coliform test in lauryl tryptose lactose broth	
E. coli	23
Klebsiella	3
Enterobacter/Serratia	2
	28
Not passing Confirmed Coliform Test	
E. coli	21
Klebsiella	3
Enterobacter/Serratia	1
Proteus rettgeri or Providencia	1
Non-Enteric	3
	29

oxidase-positive, 20% *Enterobacteriaceae* and 3.2% *Klebsiella* among randomly picked colonies. The same samples yielded no enteric viruses at the level of sensitivity [illegible]ined, 1.0 PFU/liter.

Indigenous coliphage enumerations using five *E. coli* test strains, ranged from 0 to 7400 PFU/ml in water entering the first lagoon but only 0 to 10 PFU/ml in the second lagoon.

Aerosol Determinations

Bacterial

Estimates of the background density (upwind) of airborne bacteria-bearing particles are shown in Table 7. Each figure is the mean of two estimates derived from the two Andersen samplers positioned upwind of the spray field.

Downwind bacterial aerosol concentrations at distances < 50 m were significantly above the mean value of 110.8 total bacteria/m^3 (Table 7). This was not always the case at the 200-m distance or in elevated samplers. At the 20- to 30-m distance, total aerobic bacteria-bearing particles as measured by Andersen samplers varied from 46 to 1582/m^3 above background. The mean value for all runs at this sampling distance was 485/m^3 above background. At the 41- to 50-m distance, bacterial counts ranged from 0 to 1429/m^3 above background with a mean for all runs of 417/m^3 (85% of 21-30 m mean). For the 14 runs with samples from the 200-m distance, the highest value observed was 223/m^3 above upwind. A statistical increase above corresponding upwind values could not be shown for this group of runs. The mean net observation for all samples at this distance was 37/m^3 (7.6% of 21-30 m mean). The slightly higher mean values for Anderson samplers are not significant statistically.

In a number of aerosol runs, the standard plate count/m^3 was estimated by both Andersen and Litton samplers. These estimates are shown in Table 8. The aerosol collection values are quite comparable for the two types of samplers.

A notable feature of the Andersen sampler data is the great variability (2-3 fold) observed between "replicate" samplers located in the same row and operated simultaneously (Table 9). The overall standard deviation within rows of samplers in the same run is 178, yielding a coefficient of variation (standard deviation mean) of 0.37. In contrast, the same type of samplers operated simultaneously in the laboratory aerosol chamber yielded coefficients of variation from 0.057 to 0.25 (median = 0.12). These laboratory data include both small samples (< 500 colonies distributed on 6 plates) and samples characterized by overcrowding of agar plates.

Table 7. Bacterial aerosol levels from Andersen sampler (standard plate count/m^3) at the indicated sampler locations, and net aerosol levels (observed minus simultaneous mean upwind value).

Run	Ambient air (upwind)	First row means		Second row means		200 m				Elevated			
						Obs.			Net	4.6 m		9 m	
		Obs.	Net	Obs.	Net	First	Second	Mean	Mean	Obs.	Net	Obs.	Net
1	43	534	481	477	424	126	71	99	46				
2	34	393	359	532	498	118	246	182	148				
3	43	446	403	485	442	83	95	89	46				
4	86	373	286	196	110	99	85	92	6				
5	159	979	820	658	499	62	129	96	-63				
7	134	1,362	1,228	1,292	1,158					463	329	163	29
8	90	477	387	483	393					201	111	--	--
10	69	1,049	980	832	763					224	155	92	23
11	53	285	242	274	231					133	90	117	74
12	77	234	157	267	190					170	93	76	-1
13	92	239	147	255	163					134	42	92	0
14	23	192	169	164	141					81	58	19	-4
15	65	169	104	121	56	69	80	75	9				
16	116	938	822	880	764	295	274	285	169				
17	403	967	564	800	397	311	323	317	-86				
19	189	584	395	520	331	362	412	387	198				
20	85	420	335	481	396	48	51	50	-35				
21	155	492	337	280	125	124	209	167	12				
22	112	1,314	1,202	1,128	1,[illegible]6	249	260	255	143				
24	77	535	458	380	311	180	78	129	52				
25	222	585	299	443	157	108	210	159	-127				
Mean	111	596	485	519	408			170	37	201	125	93	20

Table 8. Comparison of Andersen and Litton sample estimates (standard plate count/m^3)

Run	20-30 m (Andersen, mean)	20-30 m (Litton)	40-50 m (Andersen, mean)	40-50 m (Litton)
1			424	457
2			498	330
3	403	319		
4	286	155		
8			393	405
10	980	309		
16	822	1144		
22			1016	874
24	456	364	311	397
mean	589	458	528	493

Samples taken at 4.6 and 9 m above ground level are compared with the means of observations found at all other sampler sites in Table 8. This table shows that there was a consistent reduction in aerosol strength with elevation, with bacterial levels at the 9 m height being only slightly above background counts. Concurrent upwind samples at similar elevations were not taken, thus precluding firm conclusions.

Mean net aerosol observations have been normalized with respect to source strength in Table 10. In Figures 15-17, normalized aerosol strengths from Table 10 have been plotted against distance downwind from the nearest sprinkler heads. Similarly, in Figures 18-22 the same values are plotted against aerosol age or exposure time to normalize differences in wind speed. All runs yielding nonzero net aerosol values at 200 m are included. The slopes of bacterial aerosol reduction with time or distance are similar for most bacterial runs (i.e. runs other

Table 9. Within-row variability of Andersen sampler estimtes of total and net aerosol strength (colony-forming particles/m^3, Runs 1 - 4, 7)

Run	Sample	First row sampler 1	2	3	4	Mean	S.D.	S.D./Mean	Second row sampler 1	2	3	4	Mean	S.D.	S.D./Mean
1	Total	605	766	296	469	534	200	0.37	706	373	409	419	477	154	0.32
	Net	552	713	243	416	481	200	0.42	653	320	356	366	424	154	0.36
2	Total	509	452	191	421	393	140	0.36	749	481	502	396	532	152	0.23
	Net	475	418	157	387	359	140	0.39	715	447	468	362	498	152	0.31
3	Total	569	353	233	629	446	185	0.41	760	482	309	389	485	196	0.40
	Net	526	310	190	586	403	185	0.46	717	439	266	346	442	196	0.44
4	Total	355	495	339	300	373	85	0.23	270	145	230	141	196	64	0.33
	Net	267	408	253	214	286	85	0.30	184	58	143	55	110	64	0.58
7	Total	1,716	1,437	1,447	846	1,362	367	0.27	1,382	1,343	1,424	1,020	1,292	184	0.14
	Net	1,582	1,303	1,313	712	1,228	367	0.30	1,248	1,209	1,290	886	1,158	184	0.16
Mean	Total					622	196	0.33					596	150	0.29
	Net					551	196	0.37					526	150	0.37

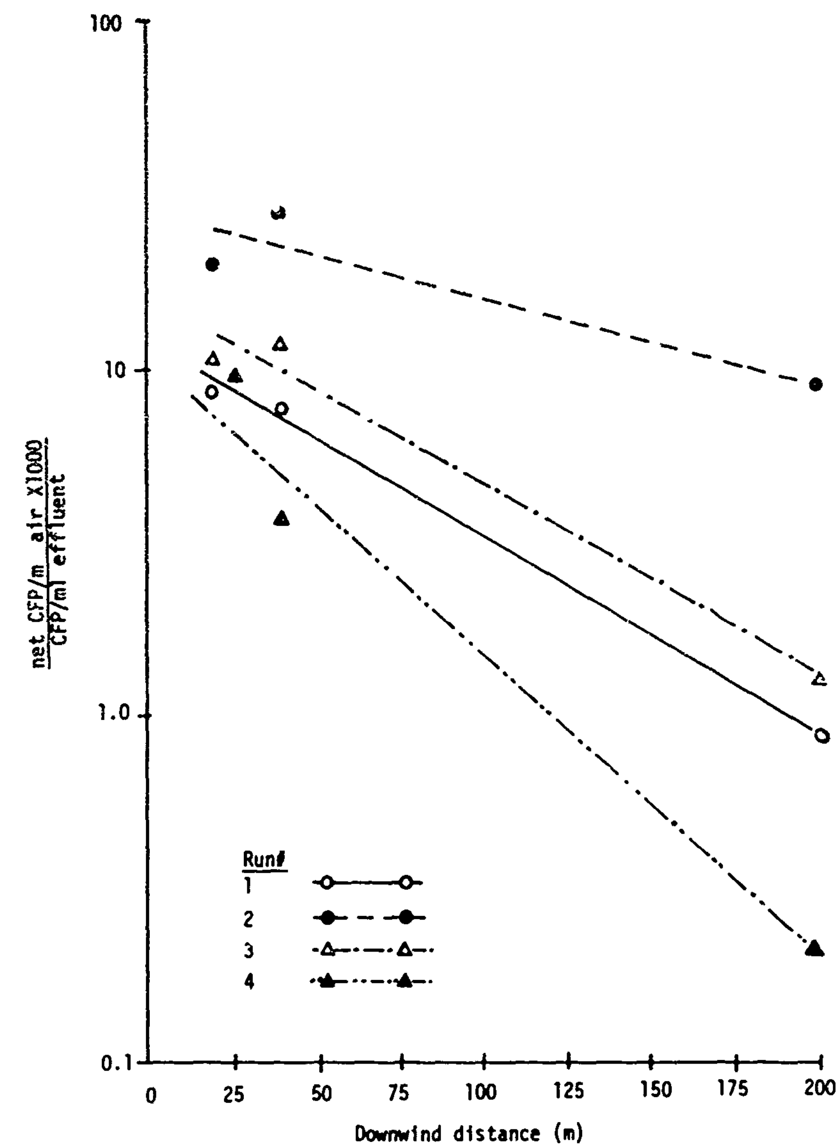


Figure 15. Relation of bacterial aerosol strength to distance downwind from nearest sprinkler heads for runs 1-4. Aerosol strength normalized to source concentration.

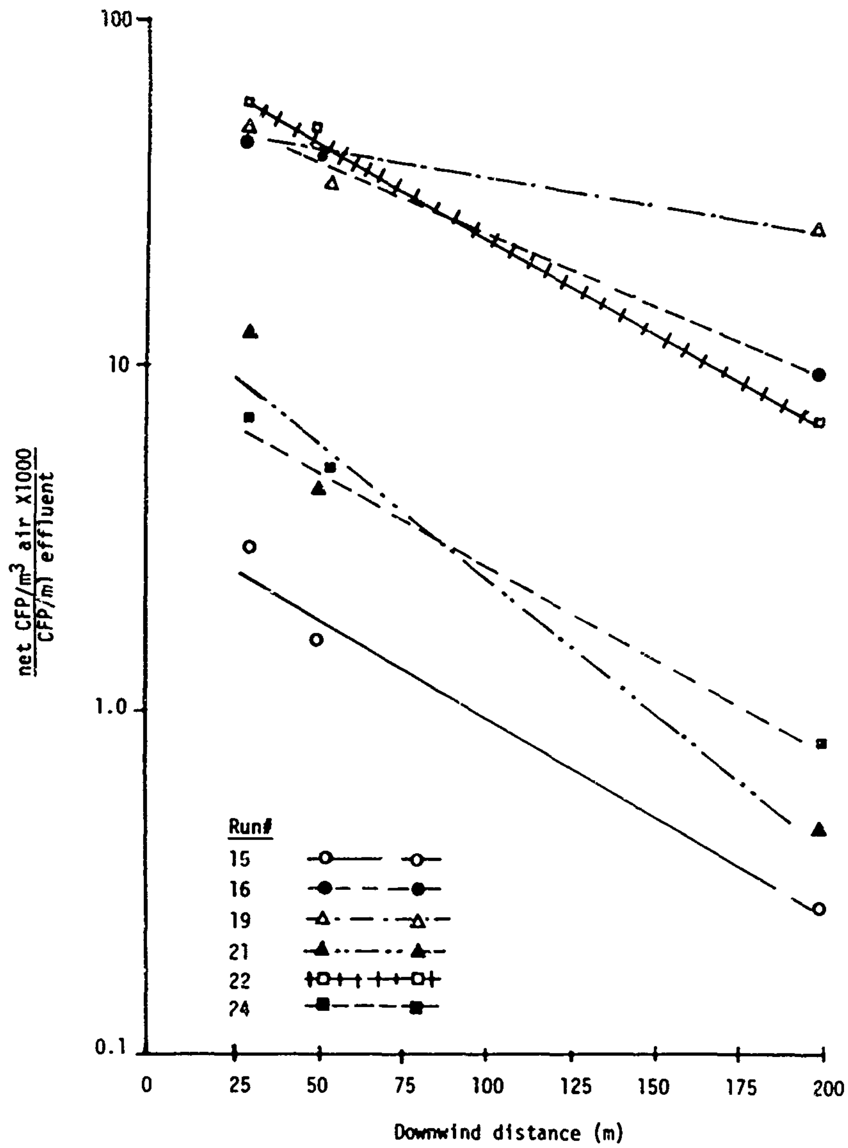


Figure 16. Relation of bacterial aerosol strength to distance downwind from nearest sprinkler heads for runs 15-24. Aerosol strength normalized to source concentration.

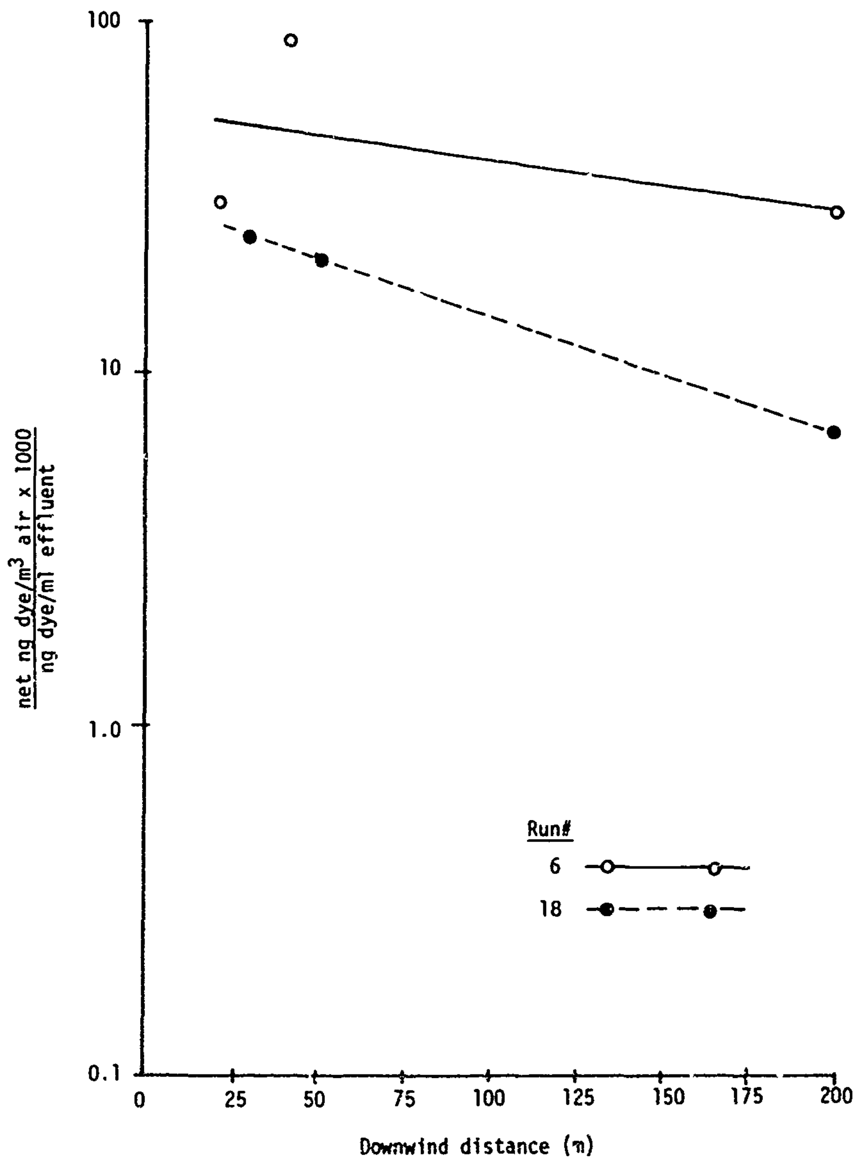


Figure 17. Relation of fluorescein aerosol strength to distance downwind from nearest sprinkler heads for runs 6, 18. Aerosol strength normalized to source concentration.

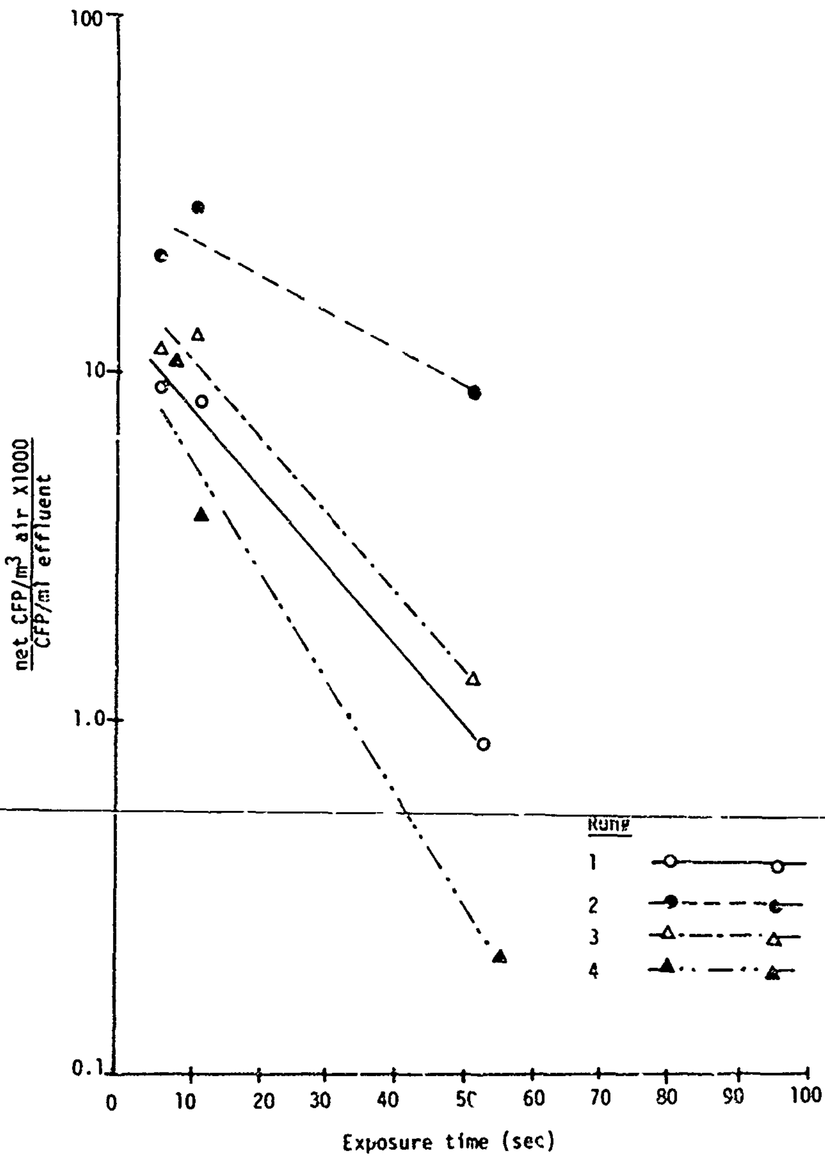


Figure 18. Relation of bacterial aerosol strength to aerosol travel time from nearest sprinkler heads for runs 1-4. Aerosol strength normalized to source concentration.

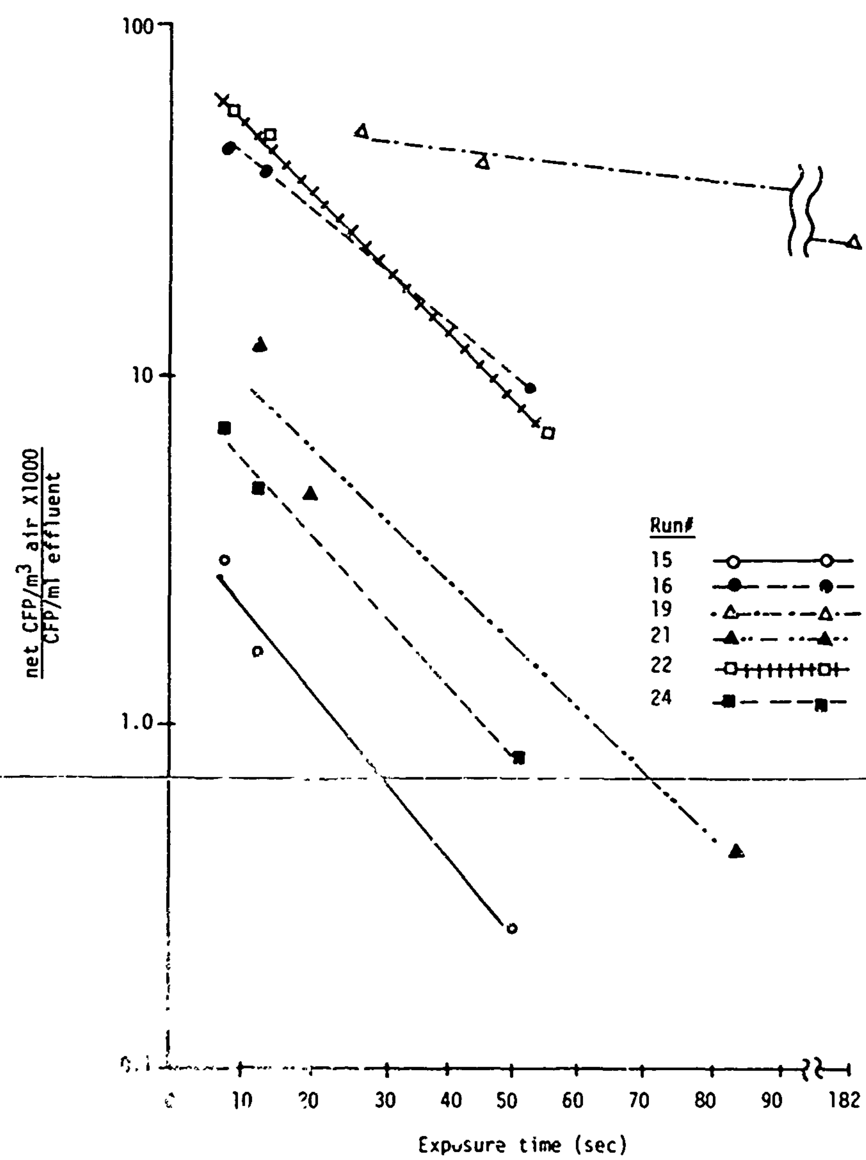


Figure 19. Relation of bacterial aerosol strength to aerosol travel time from the sprinkler heads for runs 15-24. Aerosol strength normalized to source concentration.

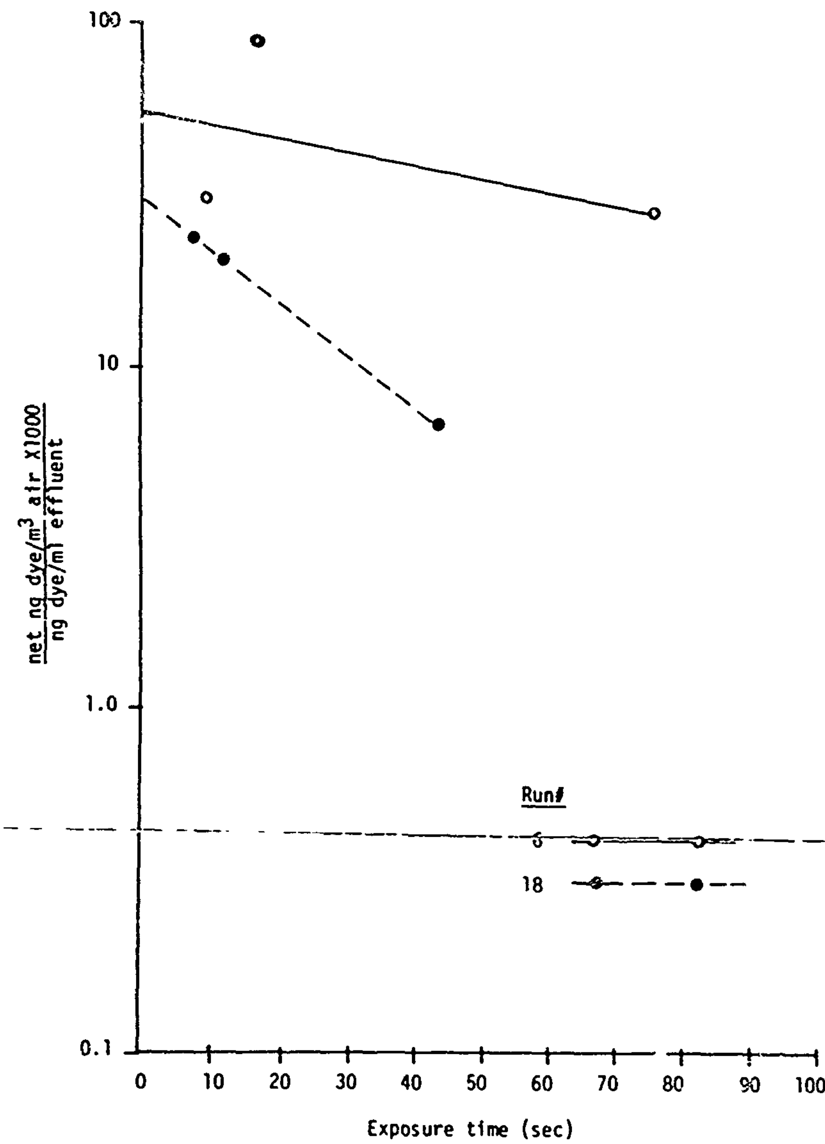


Figure 20. Relation of fluorescein aerosol strength to aerosol travel time from nearest sprinkler heads for runs 6 and 18. Aerosol strength normalized to source concentration.

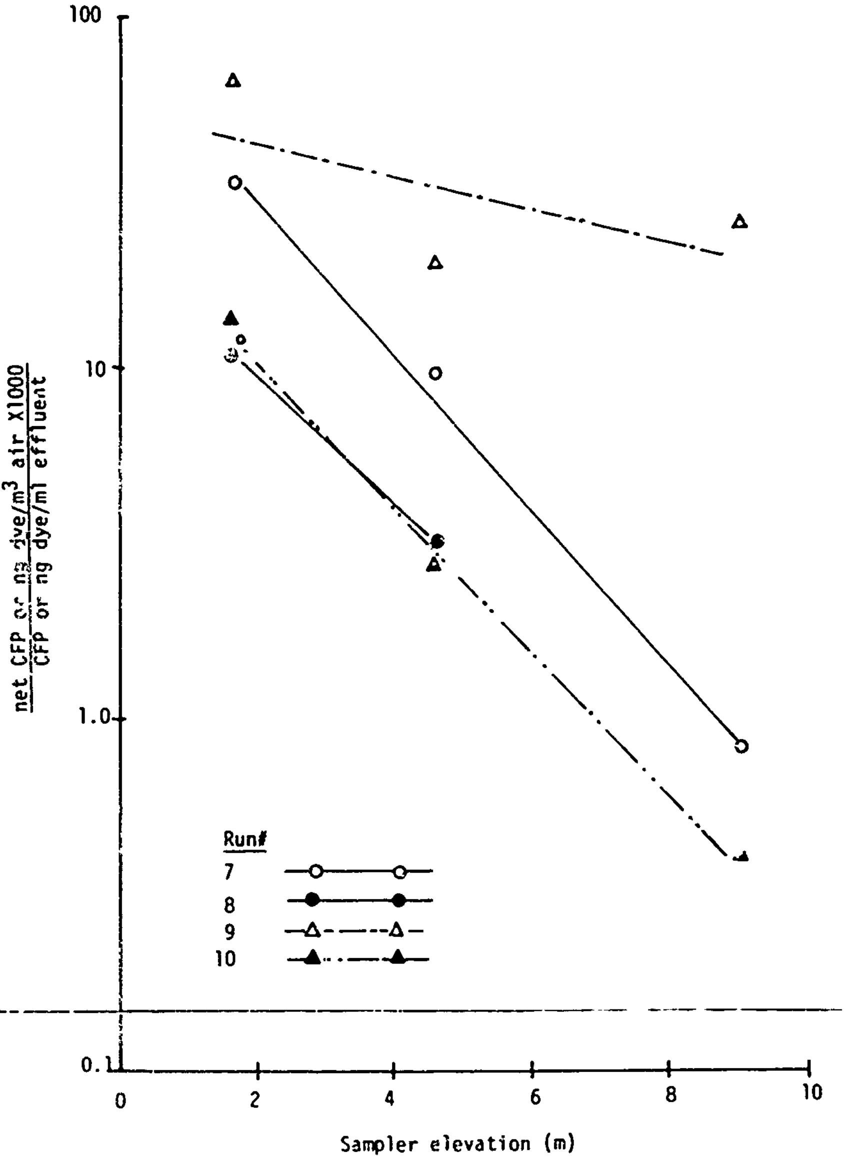


Figure 21. Relation of aerosol strength to sampler elevation runs 7, 8, and 10 (bacterial) and run 9 (fluorescein). Aerosol strength normalized to source concentration.

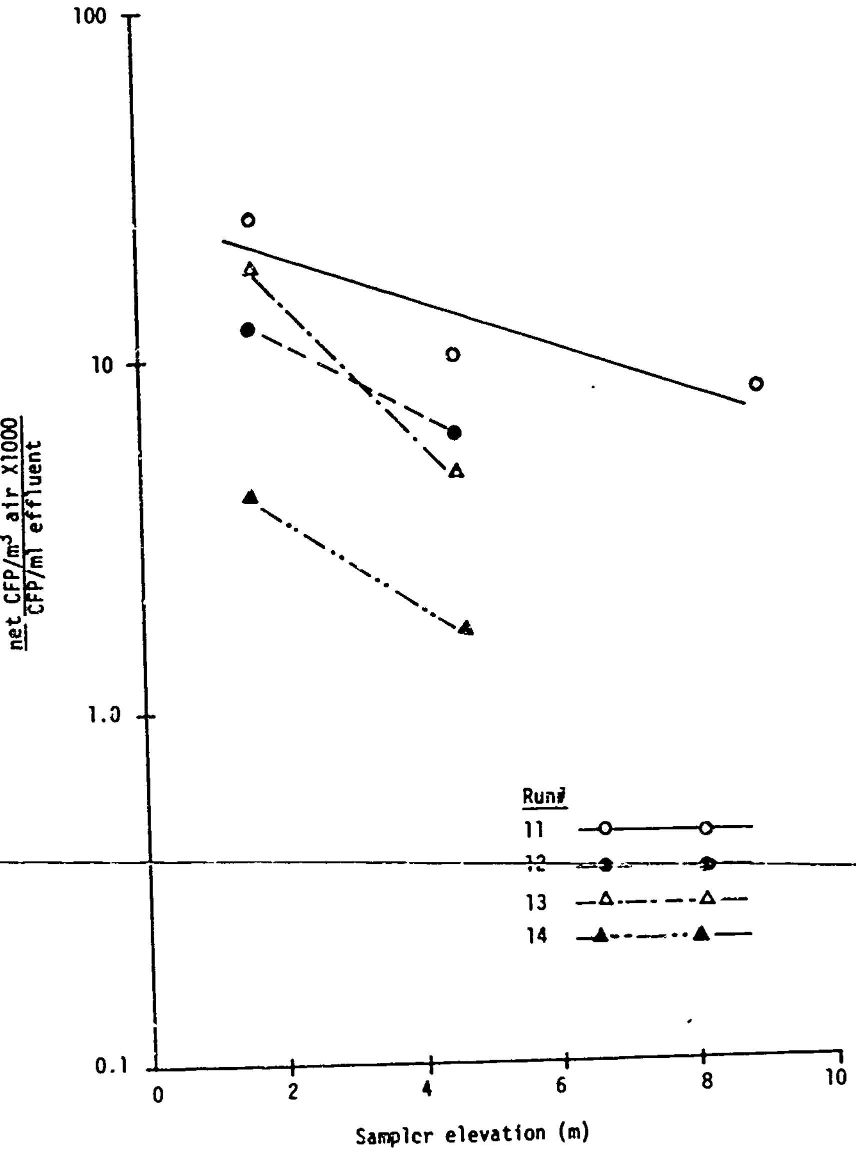


Figure 22. Relation of bacterial aerosol strength to sampler elevation for runs 11 to 14. Aerosol strength normalized to source concentration.

Table 10. Aerosol levels normalized with respect to concentration at the source (net CFP viable particles per m^3 air X 1000)/ viable bacteria per ml wastewater).

Run	First Row		Second Row		200 m	Elevated 4.6 m	Elevated 9 m
No.	(Andersen)	(Litton)	(Andersen)	(Litton)	(Andersen)	(Andersen)	(Andersen)
1	9.08		8.00	8.23	0.87		
2	21.1		29.3	19.4	8.7		
3	11.2	8.87	12.3		1.3		
4	9.86	5.34	3.76		0.21		
5	--		--		0.0		
7	36.1		34.1			9.7	0.85
8	11.1		11.2	11.5		3.2	0.0
10	16.9	5.33	13.2			2.7	0.4
11	26.9		25.7			10.0	8.2
12	10.5		12.7			6.2	0.0
13	16.3		18.1			4.7	0.0
14	4.83		4.03			1.7	0.0
15	2.97		1.60		0.26		
16	45.7	63.6	42.4		9.4		
17	33.2		23.4		0.0		
19	49.4		41.4		24.8		
20	10.8		12.8		0.0		
21	12.0		4.46		0.43		
22	57.2		48.4	41.6	6.8		
24	6.94	5.54	4.71	6.01	0.79		
25	10.3		5.41		0.0		
Mean	20.1	17.77	17.8	17.4	3.8	5.5	1.4
Median	11.6	5.54	12.8	11.5	0.61	3.2	0.0
Geometric mean	15.1	9.8	12.3	13.7		4.6	

than 6 and 18), despite wide variation in aerosol levels from run to run. Similarly, in Figures 21 and 22, where normalized aerosol concentrations at 50 m downwind are plotted against sampler elevation above ground level, the effect of elevation on bacterial aerosol strength is fairly constant for most bacterial runs.

Estimates of median particle diameters and the percentage of particles with diameters less than 5 μm are presented in Table 11. In addition, upper and lower quartile values for each distance or elevation at which Andersen samplers were deployed are presented. For ease of comparison, the data in Table 11 have been divided into two groups: those in which the optional location samples were placed 200 m downwind and those in which they were placed at 4.6 and 9-m elevations.

Table 11. Median and quartile particle diameters and percentage of particles (<5 μm) in diameter.

	Quartiles			<5 μm
	Lower	Middle	Upper	(%)
Run 1-5, 15-25				
First Row	1.58	2.46	4.12	81.7
Second Row	1.55	2.44	4.15	79.9
200 m	1.60	3.01	5.50	70.8
Upwind	2.03	4.15	7.32	52.1
Run 7-14				
First Row	1.82	2.82	4.40	78.5
Second Row	1.88	2.87	4.74	77.2
4.6 m	1.92	3.00	5.10	71.8
9.0 m	1.70	3.03	5.30	69.8
Upwind	1.97	4.59	7.50	53.1

Table 12. Aerosol level and median particle diameter: departure from ambient values.

Sampler locations	Mean aerosol level (CFP/m^3 net)	Net aerosol level upwind level (CFP/m^3)	$\Delta\partial$ Median diameter less upwind diameter (μm)	Percent <5 μm less upwind Percentage
Runs 1-6, 15-25				
First Row	490.4	3.68	-1.69	29.6
Second Row	394.6	2.96	-1.71	27.8
200 m	37	0.28	-1.14	18.7
Runs 7-14				
First Row	472.9	6.32	-1.77	25.4
Second Row	434.1	5.80	-1.72	24.1
4.6 m	125	1.67	-1.59	18.7
9.0 m	20	0.27	-1.56	16.7

Approximately 70 to 82% of bacteria-bearing particles were below 5 μm in diameter. This is an approximation of the percentage of particles in the respirable (alveolar deposition) range, i.e. 1.0 to 5 μm (Brown et al. 1950). Bacteria-bearing particles below 1 μm were generally at concentrations of 1.5 to 7% as determined from location on the lowest stage in the Andersen sampler. The data clearly indicate that the background bacterial aerosol was larger in particle size than the aerosol arising from applied wastewater. Samples from locations of low wastewater aerosol concentration, i.e. 200 m and the elevated samplers, yielded intermediate particle size values between those obtained from close downwind stations and upwind controls. Normally the background aerosol is a greater fraction of the total aerosol in regions of lower wastewater aerosol density. However, some shift of aerosol particle size characteristics in the direction of background is expected even in samples with a large contribution from aerosolized wastewater. In Table 12 the ratio of net aerosol concentration to upwind aerosol concentration at each distance or elevation is compared to the corresponding difference in median particle diameter. At close distances downwind (i.e. at first and second row stations) net aerosol levels are 3 to 6-fold greater than background levels, and median particle diameters are approximately 1.7 μm below background particle diameters. Nevertheless, in regions of low net aerosol density (i.e. at 200 m downwind and at 9-m elevation) departures from background median particle diameters are nearly as great (1.14 μm, 1.56 μm) as for the front and second row samples where the background aerosol is a small fraction of total aerosol. The final column of Table 12 gives corresponding figures for the percentage of particles below 5 μm in diameter. Again, departures from upwind values are disproportionately greater in areas of low net aerosol density (16.7-18.7 percentage points, see Table 11 for upwind and downwind percentage), when compared to values for higher density aerosols (24.1-29.6 percentage points). Thus downwind aerosols that are close to background values in numbers of particles/m^3 nevertheless display particle size properties of the wastewater-derived aerosol. This indicates that these aerosols are largely of wastewater origin.

Assignment of randomly chosen bacterial isolates, taken from SMA plates, to biochemical response groupings was accomplished according to the schema shown in Figure 14. The results (Table 13) suggest that the bacteriological spectrum after aerosolization may be different from that observed in the wastewater. Subcultures indicated an increase in the *Pseudomonas/Alkaligenes*-like and gram-positive groups and a decrease in the *Aeromonas*-like group.

Table 13. Assignment of randomly chosen bacterial isolates to arbitrary groups.

Origin of isolates	BACTERIAL GROUP									
	Gram+ rods	Gram+ cocci	Pseudomonas/ Flavobacterium-like	Acinetobacter/ Pseudomonas-like	Aeromonas/ Vibrio-like	Entero-bacteriaceae	Alkaligenes/ Pseudomonas-like	Moraxella-like	Acineto-bacter-like	Total
Source (June, 1976)	3	0	4	2	2	T	0	3	6	21
Source (simultaneous)	5	0	0	0	51	0	0	0	0	56
Andersen air samples (runs 7,8,10; 31-51 m)	13	2	3	1	11	4	5	3	2	44

Dye Runs

Sodium fluorescein was used as a tracer dye in four runs. Dye levels at the spray nozzle were fairly constant for each run, with a mean of 4.3×10^3 ng = 1 µg. Wide variability was observed in aerosol samples between individual samplers, with AGI samples showing greater variability than Litton samplers. A summary of the data, showing source strength and mean aerosol level observed at each distance, is presented in Table 14. Dye aerosol levels at the first and second row stations were generally in the range of 100-200 ng/m^3, with expected decreases occurring both downwind and with sampler elevation.

Table 14. Source and aerosol levels of dye tracer, mean values for indicated sampler distances.

Run	Dye level at nozzle (ng/ml)	Mean aerosol level ng/m^3 First Row		Second Row		200 m	Elevated 4.6 m	Elevated 9 m	Upwind
		AGI	Litton	AGI	Litton	AGI	AGI	AGI	AGI
6	3.15×10^3	56	168	392	191	88	-	-	0
9	3.34×10^3	198	210	233	194	-	65	83	0
18	6.1×10^3	79	276	127	-	42	-	-	0
23	4.6×10^3	100	162	31	181	0	-	-	0
mean	4.3×10^3	108	204	196	189	43	65	88	0

In Table 15, fluorescein aerosol levels have been normalized to source strength. The hybrid parameter used (ng dye/m^3 air)/(ng dye/ml effluent) allows comparison with the corresponding ratio for microbiological aerosols (net colony-forming particles/m^3 air)/(colony-forming particles/ml effluent) used in Table 10. The results for the two aerosols (dye and bacteria) are not strictly comparable, since the two were not measured in the same runs. Nevertheless an inspection of the geometric means of the ratios for first and second row samples reveals 2- to 3-fold greater values for the fluorescein aerosols, i.e. 23.4 to 51.7 for dye (Table 15) vs 9.8 to 15.1 for bacteria (Table 10). The difference may be attributed to biological decay (dieoff) of bacterial aerosols.

Table 15. Mean fluorescein aerosol levels normalized with respect to concentration at the source.

Run	Mean aerosol level [(ng/m³ air x 1000)/(ng/ml effluent)]						
	First Row		Second Row		200 m	Elevated	
						4.6 m	9 m
	AGI	Litton	AGI	Litton	AGI	AGI	AGI
6	17.8	53.3	124	60.6	27.9	-	-
9	59.3	62.9	69.8	58.1	-	19.5	26.3
18	13.0	45.2	20.8	-	6.9	-	-
23	21.7	35.2	6.7	39.3	0	-	-
mean	28.0	49.2	55.3	52.7	17.4	19.5	26.3
geom. mean	23.4	48.1	33.1	51.7	13.9	19.5	26.3

Fluorescein runs 6, 9 and 18 are illustrated in Figures 17, 20 and 21, in which normalized aerosol concentrations are plotted against downwind distance or aerosol exposure time. In all cases, the fluorescein runs are among those showing the lowest rates of aerosol decline compared to bacterial runs. Again, the more rapid decay in bacterial aerosols may be due to dieoff.

Sampler performance Evaluation

Table 16 presents estimates of bacterial aerosol levels obtained from Andersen samplers located side by side and operated simultaneously in a laboratory aerosol chamber. Only 6 of the 12 samples tested could be operated in a single run. In general, the results within a single aerosol run fell well within ± 20%. Agreement between samplers was comparable for both effluent wastewater and a mixture of the two enteric bacteria in dilute phosphate-buffered saline. The coefficient of variation ranged from 0.057 to 0.253.

Table 16. Simultaneous estimates of bacterial aerosol level by Andersen samplers located side-by-side within an experimental aerosol chamber.

Sampler-	E. Coli and Serratia marcescens Run (ng/ml)				Effluent Run (ng/m^3)							
Pump No.	1	2	3	4	1	2	3	4	5	6	7	8
1	49		3,290									
2	42		3,093									
3	53		3,211									
4	46		3,036									
5	24*		3,249		176	525	1,109				70*	
6	46		3,915			609		945		732		61
7		40		2,303	176	596		795			477	
8		45		3,438		643		965		621		35
9		49		3,293	205		293		919		590	
10		43		3,621			301		784	551		39
11		45		3,018	190		297		1,027		450	
12		43		3,287			331		808	641		46
Mean	43.3	44.2	3,299	3,160	186.8	593.3	305.5	953.5	884.5	636.3	505.7	45.3
Variance	16.8	9.0	100,500	215,300	190	2,460	299	16,600	12,500	5,570	5,520	130
S.D.	4.1	3.0	317	464	13.8	49.6	17.3	129	112	74.6	74.3	11.4
S.D./mean	0.087	0.068	0.906	0.147	0.074	0.084	0.057	0.135	0.126	0.117	0.147	0.253

* Sampler malfunction, not included in calculations.

Simultaneous estimates of fluorescein aerosols by AGI samplers are presented in Table 17. Samplers were also located side by side in the aerosol chamber. Variability was generally limited to $\pm$ 8%. Coefficients of variation ranged from 0.2 to 0.31.

DISCUSSION

The wastewater treated in the Deer Creek Lake project is a microbiologically weak one, and its physical and chemical characteristics are within normal range. The wastewater applied to the soil at the Deer Creek Lake site has been subjected to chlorination followed by a nominal 4-6 day residence in a second stabilization pond. This procedure may be associated with a considerable reduction in indicator organisms, and presumably in at least some pathogens, followed by regrowth of many other bacteria. This finds support in the low fecal coliform to fecal streptococcus ratio, which is not otherwise characteristic of domestic sewage. The very low coliphage levels [10 pfu/ml] observed in the second pond are a further reflection of this, precluding the use of indigenous coliphage as an aerosol marker.

The aerosol field data, averaged for all samplers and all runs, define best the bacterial or dye aerosol level at close points, i.e. 21 to 50 m downwind from the nearest (downwind) sprinklers, probably due to means being less variable than individual observations. Aerosol estimates at 200 m add an additional point on the curve of aerosol strength vs distance. Inspection of the 200-m data shows great variability from run to run, with substantial increases above upwind values in only about half of the runs (Table 7). The overall mean for net aerosol measurements, i.e. observed less upwind, at this distance is 37/m^3 (= $\sim$ 8% of mean net aerosol at 21-30 m). Yet because of difficulty in predicting in advance the optimal location for a 200-m station, the latter is far more susceptible to edge effects than close-in stations. Thus, the above estimate of 8% of 21- to 30-m aerosol strength is likely to be low.

In Figures 15-17 and 18-21, in which normalized aerosol levels are plotted against distance and exposure time, respectively, there is reasonable agreement from run to run in the slopes of aerosol decline with distance. Aerosol densities at 1.7-m elevation fell about one order of magnitude between the close sampling transects and the 200-m stations. This is in contrast to fairly wide divergence in actual aerosol densities from run to run, even when normalized to source strength.

Table 17. Simultaneous estimates of sodium flu rescein aerosol level by A T-30 samplers located side tv side within an experimental aerosol chamber.

Sampler-	Run #1			Run #2			Run #3			Run #4			Run #5		
Pump No.	Reading	(ng/ml)	(ng/m³)	Reading	(ng/ml)	(ng/m³)	Reading	(ng/ml)	9ng/m³)	Reading	(ng/ml)	(ng/m³)	Reading	(ng/ml)	(ug/m³)
1	34	7.8	2,350												
2	35	8.1	2,420										50	11.5	2,760
3	33	7.6	2,200												
4	33	7.6	2,280												
5	32	7.4	2,210										53	12.2	2,925
6	33	7.6	2,280												
7				68	15.6	3,750	65	15.0	3,588	37	8.5	2,040			
8				71	16.3	3,920	64	14.7	3,533	37	8.5	2,040	53	12.2	2,925
9				68	15.6	3,750	61	14.0	3,367	39	9.0	2,150			
10				79	18.2	4,360	67	15.4	3,698	37	8.5	2,040			
11				57	13.1	3,150	58	13.3	3,201	38	8.7	2,100	51	11.7	2,815
12				57	13.1	3,150	61	14.0	3,367	37	8.5	2,040			
Mean	33.3	7.7	2,300	66.7	15.3	3,680	62.7	14.4	3,460	37.5	8.6	2 070	51.8	11.9	2,860
S.D.	1.03			8.60			3.27			0.85			1.52		
S.D./Mean	0.03			0.13			0.05			0.02			0.03		

A steep decline in bacterial aerosol density was observed upon elevation of samplers to 4.6 m or 9 m above the ground (Table 7, Figs. 21-22). These sampler elevations were well in excess of the 2.7-m maximum height attained by the spray arc. However, the sprinkler-to-sampler tower distance, 50 to 184 m for the several sprinkler rows, was thought to be sufficient to accommodate some upward diffusion in response to turbulence factors or atmospheric instability. The results indicate that the spray field may exert a cooling and therefore an atmospheric stabilizing effect, thus reducing upward movement of air masses. It is apparent that aerosol levels at the 9-m elevated station scarcely exceed those measured upwind. However, the ambient or pre-existing aerosol at the elevated station is not known and could be less than that at the upwind (ground level) station. A possible mechanism is a washout effect occasioned by passage of the air through a spray field.

There is some agreement between runs relative to the slope of bacterial aerosol density decline with elevation (Fig. 21-22), although runs 9, 11 and 12 show a somewhat smaller effect. Greater variability in the effect of elevation might well be anticipated from one day to another, especially when wide variation in atmospheric stability is involved. In this study, however, Pasquill stability classes B, C and D were most commonly encountered (see Table A2).

The great variability observed between individual Andersen or AGI-30 samplers situated on 3-m centers at identical downwind distances in the field study stands in sharp contrast to the rather good agreement between samplers obtained with laboratory aerosols. Aerosol plume edge effects would not be anticipated to contribute to this discrepancy in view of the proximity of close sampler rows to the much larger spray field (Fig. 10). In almost all runs no major wind shifts occurred that caused aerosol plume edge effects to become a significant factor. A possible explanation for much of the sampler variability might be found in the influence of particular spray head(s) located closest to, and immediately upwind from, the sampler rows. The degree of between-sampler and within-row variability predicted by the use of plume dispersion equations might depend in part on the nature of the model used for the spray source. Thus, a source model consisting of 96 point sources separated by finite distances might predict more variability than a homogeneous field source model.

T` ` total bacterial aerosol concentrations (standard plate count) encount. ed at the Deer Creek land waste treatment site were approximately the same as those observed at Ft. Huachuca, Arizona, in the previous USAMBRDL studies (Bausum et al. 1970, Bausum et al. in prep.). However, in the present study standard plate counts at the nozzle prior to aerosolization averaged significantly lower values, $3x10^4$/ml as compared to $4x10^5$/ml. Compensating factors in this study may have been the presence of a field of many sprinklers, rather than one, and the generally higher relative humidity levels experienced.

Aerosols observed at Deer Creek presented a smaller median particle size and a higher percentage of particles falling within the "respirable" range, 1 to 5 µm, than observed at Ft. Huachuca. No explanation is evident, though the lower nozzle pressures and higher wastewater turbidity levels that were obtained at Deer Creek Lake should be considered. In Table 18 mean levels of total aerobic bacteria, indicator organisms and *Klebsiella* are compared to corresponding mean levels observed in unchlorinated and chlorinated effluent at Ft. Huachuca[7]. Differences in indicator organisms and *Klebsiella* are greater than those for standard plate count.

Table 18. Levels of total aerobic bacteria, indicator organisms and *Klebsiella* sprinkler head grab samples at Deer Creek and Ft. Huachuca, Arizona[7].

Bacterial parameter	Deer Creek	Ft. Hauchuca Unchlorinated	Ft. Hauchuca Chlorinated
Std. Pl. Count	29,000	370,000	140
Coliforms, presumptive	180	3,700	0.02
Coliform, confirmed	88	3,100	
Fecal coliforms	0.55	210	
Fecal streptococcus	0.25	1.7	
Klebsiella	20	1,900	

Knowledge of the level of any organism in the effluent prior to spraying allows establishment of an upper limit on the resulting aerosol density in the region of sampler deployment, i.e. 21-50 m or 200 m downwind. Thus, if one assumes aerosol survival for *Klebsiella* equal to that for standard plate count, the ratio (CFU/m^3 air X 1000)/(CFU/ml effluent) $\sim$ 12 can be taken (Table 10). A prediction of 0.25 viable *Klebsiella*/m^3 results. If zero dieoff is assumed, as for sodium fluorescein aerosols (Table 13), the above ratio has a value of $\sim$ 39, thereby predicting 0.8 viable *Klebsiella*/m^3.

Further evaluation of the data from the Deer Creek study will be made after predictive mathematical modeling efforts are performed. Such features as aerosolization efficiency from the field source, aerosol plume dispersion and predictions of long-distance bacterial aerosol migration will be determined. This information will be contained within a separate report. For this reason significant discussions of meteorological data and correlations with predicted plume dispersion have been omitted.

CONCLUSIONS

Bacterial aerosol levels 20- to 30-m downwind ranged from 150 to 1200 colony-forming particles/m^3. Generally there was a linear decrease in bacterial aerosol levels with distance or aerosol age and a residual level at 200 m of approximately 8% of the 30 m concentrations.

The bacterial aerosol plume 50 m downwind from the field remained near ground elevation with values at the 4.6 and 9-m heights averaging 30% and 5%, respectively. This indicates that there was little vertical aerosol dispersion.

Good reproducibility of sampler-to-sampler collection efficiency was observed in laboratory studies. Therefore, the two- to three-fold variability among replicate field samples taken simultaneously at both 30-m and 50-m downwind points indicates either poor aerosol mixing or excessive aerosol contribution from sprinklers nearest the samplers.

Field and laboratory estimates of aerosol levels made by high volume electrostatic precipitator samplers were in good agreement with those made using Andersen or AGI-30 samplers, except where aerosol levels were below the sensitivity of lower volume samplers.

At 20 to 50 m downwind from the spray field, aerosols of seeded fluorescein dye were 2-3 times greater in bacterial concentration than bacterial aerosols in relation to source strength. With all other factors being equal, these differences are estimates of biological decay (dieoff). Bacterial dieoff at the moment of aerosol formation and during the first few seconds of exposure was, however, less than one order of magnitude.

Approximately 75% of the bacteria bearing aerosol particles at 30 m downwind were within the range of pulmonary deposition (1-5 μm). The median particle diameter was 2.6 μm.

Because of the long residence time of the wastewater (~ 12 days) in the stabilization pond and chlorination, the total coliform levels in the effluent were less than 1% of the standard plate count. Measurements of total coliform levels were two orders of magnitude higher than those for fecal coliforms or fecal streptococcus levels and one order of magnitude higher than *Klebsiella* This may reflect regrowth of coliform organisms. A comparison of bacterial populations in wastewater and in aerosol samples revealed some changes in predominance of certain bacterial groups. Coliforms were a small part, less than 1.0 % of the aerosol populations, while at the same time the concentration of other bacterial groups were above background levels. These results suggest that coliforms may not be suitable indicators of the presence of pathogens in aerosolized wastewater.

In this study, the 800-m buffer zone between the land application spray field and the state park at Deer Creek Lake was more than adequate. The data indicate that, when considering aerosols distributed by meteorological events at the site studied, little if any hazardous aerosol will reach the populated area downwind if spraying of treated wastewater is restricted to periods with windspeeds of less than 6 m s^{-1} and stable conditions (class C or D).

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Appendix A: SUPPLEMENTARY DATA

Table A-1. Daily meteorological data, Deer Creek Lake, Ohio, 1 July–14 August 1976.

	MAIN METEOROLOGICAL SITE - NEAR TOWER									TOWER 50 ft.	LAGOON		
	Temp. (°C)			Precip. (mm)	Wind (m/s)*				Total				
Date July	Max[1]	Min	Avg	Total	Prev. Dir.	Speed	Sky Cover (tenths)	Evaporation DLY TOT (mm)	Solar Radiation Vert. (Langleys)	Avg. Temp (°C)	Avg. Temp (°C)	Precip. (mm)	Evap. (mm)
1	25	15	20	1.3		3.3	0.1	9.14	367	19	19	2.8	4.32
2	26	12	19			1.9	Clr	7.15	518	19	18		7.37
3	27	60	21			1.3	1.0	5.77	432	21	21		6.86
4	26	12	19			1.1	0.2	4.72	535	19	18		3.66
5	27	13	20	1.5		1.3	Clr	6.25	595	21	19	1.5	6.22
6	28	13	21			.6	Haze	5.82	MSG	21	21		5.38
7	28	15	22	4.3	SSW	1.0	1.0	3.99	555	22	21	4.3	3.12
8	29	17	23	6.1	SW	1.8	1.0	6.35	382	23	22	6.4	6.78
9	27	13	20	5.8	WNW	.9	0.1	4.60	438	22	20	5.8	4.09
10	29	16	22		S	.7	1.0	6.45	435	24	22		6.38
11	30	20	25		SW	2.2	0.7	2.79	621	27	24		5.33
12	32	21	27	7.9	WNW	2.6	0.1	13.72	774	22	27	7.9	10.26
13	26	11	18		W	1.4	0	8.41	685	19	18		7.24
14	26	13	20		SW	.9	0.8	7.21	619	24	19		7.16
15	33	17	26		SSW	2.0	0.2	7.87	544	27	26		8.26
16	33	19	26	6.4	W	1.8	1.0	8.89	300	22	26	5.8	9.35
17	26	10	18	8.9	W	1.5	Clr	6.73	661	18	18	8.9	5.59
18	24	11	18		W	.8	Clr	5.59	600	20	18		7.19
19	27	11	19		S+NW	.3	Clr	6.02	631	21	19		5.56
20	28	15			SSW	.5	0.3	5.87	464	22	21		5.64
21	29	19			SSW[3]	1.7	1.0	6.55	363	24	23		7.37
22	31	20		10.2	MSG	1.1	1.0	4.55	299	23	25	11.4	5.97
23	27	21	2	3.8	MSG	.7	0.5	1.09	589	26	24	5.1	.43
24	33	20	27	6.4	MSG	1.[illegible]	0.8	9.27	511	24	26	9.4	12.7
25	29	12	21		MSG	.9	0.1	6.81	645	26	21		5.23
26	28	13	21		MSG	.4	Clr	5.59	638	23	21		6.91
27	28	18	23		MSG	.6	1.0	5.99	394	24	21		6.86
28	30	18	24	20.3	SSW	.8	1.0	3.35	518	24	24	20.3	4.17
29	29	20	24	16.5	SSW	1.2	1.0	21.59	378	24	24	16.5	22.61
30	29	19	24	4.3	NW	1.3	1.0	8.97	512	24	24	4.3	6.71
31	28	16	22		W	.4	1.0	4.60	484	23	26		5.23
Avg.	28	16	22	103.4 Total	SSW	1.3 m/s		212.50 Total	516 Avg.	22	22	110.5	209.95

Table A-1 (cont'd)

Date Aug.	MAIN METEOROLOGICAL SITE - NEAR TOWER Temp. (°C) Max[1]	Min	Avg	Precip. (mm) Total	Wind (m/sec)* Prev. Dir.	Speed	Sky Cover (tenths)	Evaporation DLY TOT (mm)	Total Solar Radiation Vert. (Langleys)	TOWER 50 ft. Avg. Temp (°C)	LAGOON Avg. Temp (mm)	Precip. (mm)	Evap. (mm)
1	29	13	21		NW	1.3	0.5	6.45	586	19	22		5.18
2	24	10	17		N	.7	0.1	5.23	624	17	18		7.10
3	25	8	17		NW	.7	0.1	6.58	636	16	17		6.05
4	25	9	17		SSW	.4	Clr	5.59	457	18	17		5.31
5	27	16	21	T	SSW	.10	1.0	5.28	495	23	22	T	5.66
6	29	18	23	1.3	MSG	1.5	1.0	6.45	113	19	24	1.3	4.09
7	22	16	19	34.5	NW	1.5	1.0	.23	143	13	19	34.8	1.57
8	20	9	14		NW	1.6	0.8	2.74	531	16	14		1.70
9	23	11	17		NW	.6	Clr	4.11	591	18	17		4.19
10	26	10	18		SW	.7	Clr	5.82	589	20	20		4.65
11	28	12	20		S	.5	0.2	5.16	577	21	21		6.10
12	29	18	23		SSW	.9	1.0	5.72	503	24	23		5.59
13	30	19	24	.8	MSG	1.3	1.0	4.98	539	23	24	.8	5.13
14	27	18	23	2.3	MSG	1.0	1.0	5.77	343	22	23	1.8	6.96
Avg.	26	13	19	38.9 Total		1.0		70.11 Total	480 Avg.	19	20	38.7'	69.28

1 Maximum temperatures are usually for previous day.
2 Observation time 0800 Local Standard Time.
3 Missing equipment failure.
* Avg daily wind velocity near ground over evaporation pan.

Table A-2. Deer Creek Lake, Ohio meteorological summary during sampling runs July and August 1976.

				2 Meters			Tower - 20 Meters			Observation Bldg.		
				Air Temp(°C)		RH(1)	Air Temp(°C)			Solar Radiation Langleys	Wind(2)	
Run #	S.C.(5)	Date July	Time LST.	Start	Finish	(%)	Start	Finish	RH%	g-cal/cm^2	(m/sec)	Sky Cover & Remarks(4)
1	C	14	1207-1227	26.7	27.2	64	24.4	26.7	56	2.10	SSW-4	OVC Ci, Hazy
2	C	14	1456-1516	30.1	31.6	56	30.3	30.1	53	MSG[3]	SSW-6	OVC Ci, Hazy
3	B	15	1219-1239	31.2	31.2	70	29.4	29.4	60	2.10	SSW-4	1/10 Ci, 9/10 haze
4	C	15	1626-1646	32.1	32.6	52	29.7	31.1	43	1.03	SSW-4	8/10 Cu.
5	C	17	1132-1152	20.1	21.0	63	20.0	20.3	59	0.75	NW-2	5/10 Cu.
6	B	17	1406-1427	22.7	22.7	52	20.0	20.3	59	2.20	SSW-2	5/10 Cu.
7	D	20	1059-1119	25.3	25.4	68	24.7	25.1	53	MSG	SSW-6	OVC Ac
8	D	20	1348-1408	26.7	26.9	64	25.8	26.1	47	MSG	SSW-6	OVC Ac
9	D	20	2101-2121	22.5	21.8	95	24.4	24.4	58	0.0	S -1	1/10 Ci Nightime test
10	C-D	21	1134-1154	24.4	23.3	74	24.7	24.3	73	1.64	SSW-4	OVC cs
11	B-C	28	1207-1227	27.2	27.4	70	26.2	26.4	63	1.60	SW-2	9/10 Cu
12	C	28	1347-1407	27.9	18.1	74	27.1	27.2	59	2.02	SSW-3	OVC Ci breaks in OVC
13	C-D	28	1553-1613	28.0	27.8	72	27.7	27.7	60	1.48	SSW-4	OVC Ac breaks in OVC
14	D	29	1205-1225	22.2	22.2	88	22.2	22.2	82	0.30	W -3	OVC Sc
15	C-D	29	1529-1549	25.4	25.4	69	26.6	26.8	65	1.86	SSW-4	6/10 Cu and Ci
		Aug										
16	B-C	5	1121-1141	22.5	23.7	80	20.6	21.4	72	1.60	S -4	7/10 Ac
17	D	5	1431-1451	27.4	28.0	49	25.8	25.8	44	1.60	SW -7	7/10 Cu, Hazy
18	C-D	5	1636-1656	27.9	27.8	46	26.9	26.8	42	1.36	SSW-4	8/10 Cu, Hazy
19	D	5	2151-2211	21.8	21.5	93	23.5	23.1	70	0.00	SSW-1	7/10 Ac Nighttime test
20	C	10	1139-1159	23.9	24.2	48	23.1	23.3	45	1.92	W -2	Clear
21	A	11	1105-1125	24.3	24.9	65	23.1	23.6	55	1.84	S -2	1/10 Ci Hazy
22	B-C	12	1135-1155	25.9	26.9	73	25.0	25.0	62	1.78	SSW-3	9/10 Cc Hazy
23	C	12	1238-1258	27.9	28.3	62	25.1	26.2	55	1.84	SSW-4	9/10 Cc Hazy
24	B	12	1520-1540	29.3	29.4	50	27.6	27.6	50	2.20	SW -3	4/10 Cu, 6/10 Cs, OVC
25	C-D	12	1735-1755	27.8	27.8	64	28.1	28.1	49	0.62	SSW-2	8/10 Cc

(1) R.H. = Relative Humidity
(2) Wind = 2 Meters at start of test
(3) Missing data - equipment failure

(4) Cloud Symbols: Ci = Cirrus, Cs = Cirrostratus, Cc = Cirrocumulus
Ac = Altocumulus, Cu = Cumulus
OVC = Overcast

S.C. = Stability Class
(5) A most unstable condition
D most stable condition

Table A-3. Wind summary, Deer Creek Lake, Ohio during test runs 1-25, 14 July-12 August 1976.

Date	Run#	Time (LST)	Tower Site (2 Meters) Prevailing Direction	Velocity (m/sec) Max.	Min.	Ave.	Tower Site (20 Meters) Prevailing Direction	Velocity (m/sec) Max.	Min.	Ave.	Operations Bldg. (2 Meters) Prevailing Direction	Velocity (m/sec) Max.	Min.	Ave.
July														
14	1	1207-1227[1]	214	5	3	4	207	6	3	5	206	msg.[2]	msg.	msg.
14	2	1456-1516	212	5	5	4	205	7	7	5	204	msg.	msg.	msg.
15	3	1219-1239	223	5	3	4	219	7	3	5	218	msg	msg.	msg.
15	4	1626-1646	265	6	3	5	258	8	3	6	262	msg.	msg.	msg.
17	5	1132-1152	293	5	1	3	msg.[2]	6	2	4	283	msg.	msg.	msg.
17	6	1406-1427	276	4	1	3	msg.	5	1	3	262	msg.	msg.	msg.
20	7	1059-1119	221	6	3	5	msg.	8	5	7	223	8	4	6
20	8	1348-1408	237	7	3	5	msg.	7	5	5	229	6	3	5
20	9	2101-2121	208	2	1	2	msg.	4	3	4	209	2	1	2 [2]
21	10	1134-1154	234	5	2	4	230	6	3	5	232	5	2	4
28	11	1207-1227	236	4	2	3	237	6	3	5				
28	12	1347-1407	211	4	2	3	207	7	3	5	Winds discontinued at observation building.			
28	13	1553-1613	212	6	2	4	211	8	3	6				
29	14	1205-1225	260	5	2	4	252	9	5	7				
29	15	1529-1549	236	5	2	4	245	9	5	7				
Aug.														
5	16	1121-1141	214	7	7	5	219	6	4	5				
5	17	1431-1451	228	8	3	6	231	10	5	8				
5	18	1636-1656	224	7	3	5	230	8	3	6				
5	19	2151-2211	209	2	0	1	209	3	2	3				
10	20	1139-1159	288	4	2	3	295	5	4	5				
11	21	1105-1125	196	3	1	2	192	4	2	3				
12	22	1135-1155	221	6	3	5	224	7	4	6				
12	23	1238-1358	230	6	3	5	238	7	4	6				
12	24	1520-1540	231	6	2	4	233	8	3	6				
12	25	1735-1755	211	4	2	3	213	5	3	4				

1. Minute by minute winds during testing are on file at USACRREL and USAMBRDL.
2. Lightening blew out translator

Table A-4. Spray area* water application observations - 12 plastic containers A-L.

	PLOT 1 - TREE AREA						PLOT 2 - GRASS AREA						PLOT 3 - SOYBEAN AREA						PLOT 4 - GRASS AREA						
	A		B		C		D		E		F		G		H		I		J		K		L		
July	mls	mm	mls	mm	mls	mm	mls	mm	mls	mm	mls	mm	mls	mm	mls	mm	mls	mm	mls	mm	mls	mm	mls	mm	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	3	.3	13	.8	.21	1.3	.9	.5	.17	1.0	17	1.0	9	.5	11	.8	11	.8	19	1.0	14	.8	21	1.3	Rain
7	59	3.3	63	3.6	69	3.8	73	4.1	59	3.3	65	3.8	23	1.3	70	4.1	63	3.6	51	2.8	81	4.6	75	4.3	Rain
8	101	5.8	101	5.8	105	5.8	109	6.1	78	4.3	100	5.6	53	3.0	101	5.8	97	5.6	97	5.6	95	5.3	89	5.1	Rain
9	123	6.9	123	6.9	137	7.9	126	7.1	137	7.9	138	7.9	MSG	MSG	130	7.4	149	8.4	103	5.8	119	6.9	210	6.9	Rain
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
12	125	7.1	135	7.6	115	6.6	129	7.4	93	5.1	130	7.4	MSG	MSG	133	7.6	128	7.4	121	6.9	MSG	MSG	133	7.6	Rain
13	0	0	0	0	0	0	0	0	0	0	0	0													
14	0	0	0	0	0	0	0	0	0	0	0	0													Run 1 & 2
15	48	1.8	17	1.0	91	5.1	58	3.3	94	5.3	48	2.8													Run 3
15	106	6.1	60	3.3	115	6.	103	5.8	142	8.1	133	7.6													Run 4
16	181	10.2	197	11.6	163	9.1	173	9.9	200	11.4	201	11.4													Rain
16	108	6.1	52	3.0	84	4.8	106	6.1	97	5.6	54	3.0													Run 5
17	105	5.8	40	2.3	92	5.3	120	6.9	130	7.4	56	3.3													Run 6
20	45	2.5	15	.8	72	4.1	38	2.3	60	3.3	59	3.3													Run 7
20	28	3.5	10	.5	52	3.0	26	1.5	58	3.3	35	2.0													Run 8
20	MSG	MSG	MSG	MSG	MSG	MSG	MSG	MSG	MSG	MSG	MSG	MSG													Run 9
21	50	2.8	15	.8	91	5.1	41	2.3	84	4.8	68	3.8													Run 10
22	264	15.0	226	12.7	291	16.5	243	13.7	140	7.9	243	13.7													Rain
23	86	4.8	90	5.1	95	5.3	88	5.1	100	5.6	97	5.6													Rain
28	55	3.0	30	1.8	100	5.6	60	3.3	33	1.8	55	3.0													Runs 11-13
29	159	8.9	119	6.9	200	11.	180	10.6	63	3.6	162	9.1													Run 14
Aug																									
3	71	4.1	32	1.8	81	4.6	75	4.3	150	8.4	123	6.9													Run 15
5	153	8.6	161	9.1	187	10.7	163	9.1	110	6.4	127	7.1													Runs 16-19
10	26	1.5	16	1.0	49	2.8	26	1.5	54	3.0	35	2.0													Run 20
11	17	1.0	30	1.8	29	1.5	30	1.8	27	1.5	16	1.0													run 21

* Spray area approx 170 m across
A-L locations plotted on Figure 2.
mls = milliliters
MSG = Missing data

Table A-5. Chemical and physical wastewater parameters concentrations in mg/liter of different constituents in wastewater collected from Point 3 (effluent used as spray irrigation).

Date	pH units	BOD	Total P	Chlorides	NH_4^+-N	NO_2-N	NO_3-N	TKN	Organic N	Hard-ness	Fecal Coliforms /100 ml	Fecal Strepto-coccus /100 ml
6/4	8.20	----	.099	58.61	0.43	0.00	0.39	11.40	10.58	----	6	10
6/9	8.15	5.20	.027	64.00	0.18	0.01	1.01	3.51	2.31	----	4	32
6/12	8.00	6.45	.355	62.25	0.00	0.00	0.56	4.91	4.35	----	17	3
6/15	8.00	----	----	79.09	0.00	0.02	2.03	1.54	----	----	372	90
7/14	8.65	8.25	.258	82.60	0.06	0.01	0.26	1.49	1.16	178.7	64	180
7/14	8.80	7.20	.322	79.30	0.00	0.01	0.06	1.49	1.42	194.2	20	200
7/15	8.55	9.60	.263	87.30	0.00	0.01	0.06	1.15	1.08	174.8	70	---
7/15	8.65	8.10	.411	85.80	0.00	0.01	0.00	1.85	1.84	190.3	40	---
7/15	8.75	7.80	.502	----	0.00	0.02	0.00	1.62	1.60	----	--	---
7/20	7.90	---	.204	----	0.00	0.00	0.05	1.94	1.89	190.3	30	---
7/20	8.00	---	.177	----	0.00	0.00	0.08	1.91	1.83	190.3	20	---
7/21	7.86	---	.199	----	0.00	0.00	0.16	2.04	1.98	194.2	0	---
7/28	8.15	5.55	.221	85.00	0.00	0.01	0.00	2.17	2.10	174.8	70	420
7/28	8.05	5.55	.202	42.26	0.06	0.02	0.03	1.89	1.85	178.7	80	400
7/28	8.10	5.10	.212	82.64	0.07	0.01	0.00	1.91	1.83	182.5	90	560
7/29	---	5.55	.150	82.64	0.00	0.01	0.00	1.52	1.51	178.7	20	290
7/29	8.10	4.95	.161	85.00	0.09	0.01	0.00	1.58	1.48	186.4	40	710
8/5	8.35	4.95	.258	88.77	0.00	0.00	0.00	1.81	1.81	194.2	0	22
8/5	8.45	4.83	.320	87.83	0.00	0.00	0.00	1.63	1.63	198.0	0	0
8/5	8.50	4.95	.245	88.77	0.00	0.00	0.00	1.42	1.42	178.7	0	22
8/11	8.40	7.08	.199	86.41	0.00	0.00	0.00	2.19	2.19	174.8	22	800
8/11	8.40	---	.210	87.36	0.00	0.00	0.00	2.32	2.32	167.0	20	70
8/12	8.25	7.95	.229	89.72	0.00	0.00	0.00	2.27	2.27	174.8	20	800
8/12	8.30	8.79	.257	88.30	0.00	0.00	0.00	2.32	2.32	170.9	20	1090
8/12	8.47	8.64	.268	92.55	0.00	0.00	0.00	2.45	2.45	163.1	20	777

Above samples were collected during period of aerosol studies and assayed at the Agronomy Department, Ohio State University, Columbus, Ohio.

Table A-6. Chemical and physical wastewater parameters Concentrations in mg/liter of Total Solids (TS), Total Volatile Solids (TVS), Suspended Solids (SS), Volatile Suspended Solids (VSS), Total Soluble Solids (TSS), and Total Volatile Soluble Solids (TVSS) in wastewater collected from point 3 (effluent used as spray irrigation).

Date	TS	TVS	SS	VSS	TSS	TVSS
6/4/76	472	125	95.00	20.00	377.00	105.00
6/9/76	490	115	73.00	18.00	417.00	97.00
6/12/76	641	122	235.00	50.00	406.00	72.00
6/15/76	985	210	318.00	53.00	667.00	157.00
7/14/76	872	137	160.00	45.00	712.00	92.00
7/14/76	510	130	115.00	40.00	395.00	90.00
7/14/76	543	125	25.00	5.00	518.00	120.00
7/15/76	515	160	130.00	50.00	385.00	110.00
7/29/76	370	65	221.43	-----	148.57	------
7/29/76	550	75	171.43	-----	328.57	------
7/29/76	515	90	264.29	-----	250.71	------
7/30/76	455	60	71.43	-----	383.57	------
7/30/76	435	40	71.43	-----	363.57	------
8/5/76	569	100	228.57	45.71	340.43	54.29
8/5/76	652	99	292.85	52.85	359.15	46.15
8/5/76	526	81	150.00	32.00	376.00	49.00
8/11/76	503	139	102.67	46.67	97.37	92.33
8/11/76	416	147	106.67	25.33	309.33	121.67
8/12/76	555	145	148.00	22.67	407.00	122.33
8/12/76	541	139	185.33	38.67	355.67	100.33
8/12/76	643	161	238.67	46.67	404.33	114.33

Above samples were collected during period of aerosol studies and assayed at the Department of Agronomy, Ohio State University, Columbus, Ohio.

Table A-7. Chemical and physical wastewater parameters.

Average concentrations of different constituents in mg/liter in wastewater collected from Point 3 (effluent used as spray irrigation).

Constituents	No. Samples	mg/liter
pH	24	6.290
BOD	19	6.650
Total Phosphorous	24	0.239
Chlorides	21	80.290
NH_4^+-N	25	0.030
NO_2-N	25	0.005
NO_3-N	25	0.187
Total Nitrogen	25	2.413
Organic Nitrogen	25	2.303
Hardness (EDTA)	20	181.770
Fecal Coliforms	20	44/100 ml
Fecal Streptococcus	19	341/100 ml
Total Solids	21	559.900
Total Volatile Solids	21	117.380
Suspended Solids	21	162.000
Volatile Suspended Solids	16	37.020
Total Soluble Solids	21	381.020
Total Volatile Soluble Solids	16	96.370

Above samples were collected during period of aerosol studies and assayed at the Agronomy Department, Ohio State University, Columbus, Ohio.